Modelling Manufacturing Systems Flexibility

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ABSTRACT

The flexibility to change product and processes quickly and economically represents a significant competitive advantage to manufacturing organisations. The rapid rise in global sourcing, has resulted in manufacturers having to offer greater levels of customisation, thus a wider product range is essential to an organisation's competitiveness. The rate at which new products are introduced to the market has also increased, with greatly reduced development times being essential to a new product's market success. Hence there is a strong need to have a flexible manufacturing system such that new products may be introduced rapidly. These drivers have made the need for flexibility within manufacturing systems of great importance. However, there are many types of flexibility and to ensure that organisations correctly target these types of flexibility there is a need to measure flexibility, because, measuring flexibility allows manufacturers to identify systems which will improve their performance.

This research, therefore, has focused on the development measures for two types of flexibility i.e. mix flexibility and product flexibility. These represent the ability to change between the manufacture of current products i.e. mix flexibility and the ability to introduce new products i.e. product flexibility. In order to develop effective measures for these types of flexibility a conceptual model has been developed, which represents the current and potential future product range of manufacturing systems.

The methodology developed for measuring mix and product flexibility has been successfully applied in two companies. These companies represent diverse manufacturing environments. One operates in high volume chemical manufacture and the other in low to medium volume furniture manufacture. Through applying this methodology in these two companies it has been demonstrated that the methodology is generic and can be used in a wide range of companies.

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GLOSSARY

$\underset{\sim}{\alpha}$	Indicates that set α is fuzzy
α_A	Set of manufacturing system states for potential products that can be manufactured by changes in data in the manufacturing system.
α_B	Set of manufacturing system states for potential products that can be manufactured by low cost changes to the manufacturing system.
α_C	Set of manufacturing system states for potential products that can be manufactured by moderate to high cost changes to the manufacturing system.
β	Set of manufacturing system states for actual products
AGV	Automated Guided Vehicle
CM	Cellular Manufacture
Dur_i	Set-up duration of product *i*
FMM	Flexible Manufacturing Module
FMS	Flexible Manufacturing System
IRR	Internal Rate of Return
JIT	Just In Time
MSTC	Mean Sensitivity To Change
$MSTC_J$	Mean Sensitivity To Change of an individual machine within a system
$MSTC_T$	Mean Sensitivity To Change of a system of parallel machines
$MSTC_Y$	Mean Sensitivity To Change of a system of series machines
n/a	Not applicable
n/p	Not possible
P_i	Probability of product *i* occurring
QA	Quality Assurance
QC	Quality Control
ROI	Return on Investment
SD	Standard deviation of Sensitivity To Change
SD_J	Standard deviation of Sensitivity To Change of an individual machine within a system
SD_T	Standard deviation of Sensitivity To Change of a system of parallel machines
SD_Y	Standard deviation of Sensitivity To Change of a system of series machines
U	Universe of all products
WCM	World Class Manufacturing

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1. INTRODUCTION

Flexibility has two meanings, the ability to bend and the ability to adapt. It is the latter meaning that is applicable to manufacturing systems. In this respect a manufacturing system must have the ability to adapt to changing internal and external influences such as customer demands.

1.1 The Importance of Flexibility

The ability to adapt has caused manufacturing flexibility to be an area of interest for industrialists for many years, (Mandelbaum and Buzzacott 1986). It has been highlighted as of particular importance in the 1980's (Zelenovich and Dragutin 1982) and 90's (Slack and Correa 1992; Garwood 1990). This is further reflected in the survey by De Meyer, Nakane, Miller and Ferdows (1989) of manufacturing futures, who identified flexibility as '*the next competitive battle*'.

Flexibility has become important in recent years because of the change in the competitive environment faced by manufacturing organisations. For example product life cycles have become shorter, customers expect a wider choice of products, and the globalization of manufacturing means there are many more manufacturers entering the market (Kidd, 1994). Shorter product life cycles require flexibility in manufacturing systems so that the system can easily adapt to new products (Chen, Catalone and Chun, 1992). Offering a wider range of products to the customer, (without increasing stock levels), requires a more flexible manufacturing system to allow production changes between existing products. Increased globalization results in companies' having to increase their competitiveness; flexibility in manufacturing systems can aid this by allowing the manufacturing system to deal robustly with unexpected occurrences such as machine breakdown, whilst minimising additional costs.

The need for flexibility is not limited to the manufacturing function. It is important in all areas of the manufacturing company from design, (Pandiarajan and Putan, 1994) through to logistics (Daugherty and Pittman, 1995) and at all levels, including personnel (Goyal and Gunasekaran, 1995) and infrastructural flexibility (Slack and Correa, 1992). In addition, flexibility has been cited as a desirable characteristic for products, services (Anon, 1986; Harvey, Lefebvre and Lefebvre, 1997) and people (Atkinson, 1985). The need for flexibility has also affected a wide range of industries including semi-conductor manufacture (Pandiarajian and Putan, 1994; Chen et al., 1992) process industries (Upton, 1995; Thilander, 1992 and Hendry, 1985), and the manufacture of consumer durables (Tighe, 1993).

1.2 Benefits of Flexibility

Many of the benefits of flexibility can be related to specific types of flexibility. These are discussed at greater length in Section 2.5.1, however, this section takes a more general approach.

Slack (1990) has identified a number of reasons how organisations may benefit from greater flexibility:

a. to cope effectively with a wide range of existing parts, components or products,

b. to adapt products to the specific requirements of customer,

c. to adjust output levels to be able to cope with demand variations such as seasonal fluctuations,

d. to expedite priority orders though the plant,

e. to cope with plant breakdowns,

f. to provide adjustments in capacity when demand is very different from forecast,

g. to cope with failure of suppliers (internal and external),

h. so that future generations of product can be manufactured on the same plant,

i. because there is no clear idea about how much capacity will be needed in the future, and

j. because there isn't any accepted forecast or plan for the future, so options need to be kept open.

Slack has provided a comprehensive list of benefits, however, it can be anticipated that individual companies in different business areas may have other industry specific reasons for wanting flexibility. For example in the food industry, raw materials such as flour can vary in specification. There is a need to have a manufacturing process that is flexible enough to cope with these variations in specification and still produce a consistent product.

1.3 Initial Attempts at Improving Flexibility

In response to the increased interest in flexibility, flexible manufacturing systems (FMS's) were developed, with many manufacturers considering FMS as the principal method of achieving flexibility (Nagarkar and Bennet, 1988).

This, however, proved to be a limited view and a number of practitioners demonstrated this by achieving flexibility using alternative methods such as strategic use of CNC machines (Kellock, 1985), cellular manufacture (Hutchinson 1984) and computerised shop floor control systems (Holmgren 1988). The initial faith placed in the ability of FMS's to provide flexibility also lessened as companies installed FMS's and discovered their shortcomings. This disappointment arose partly because the performance of FMS's was rarely quantified in terms of flexibility before or after installation and thus no improvement in flexibility could be demonstrated. This is illustrated by Diesch and Matsrom (1985) who assess the performance of an FMS in terms of down-time, but neglect flexibility.

The limited achievement towards increased flexibility is identified by Gerwin (1989) who states "*The most successful FMS's are matched sets of machines and parts flexible only within a strictly limited repertoire*". Jaikumar (1986) also highlights the lack of flexibility in many FMS's. This is supported by practitioners such as Stokes (1982) who states with regard to FMS's flexibility "*It is not the answer to a maiden's prayer and it should not be assumed that any part you like can be made at the drop of a hat*!". However, this focus on flexibility often led companies who had installed FMS's that failed to fulfil flexibility requirements, to deal with the need for flexibility in alternative ways. For example Tombak and DeMeyer (1988) concluded that a better approach is to reduce the need for flexibility and reduce the number of product lines.

1.4 Difficulties in Measuring Flexibility

The desire to achieve flexibility through FMS's or alternative methods drove the need for more precise flexibility definitions and measurements. The lack of definition and the misunderstanding of the nature of flexibility is outlined by Hill and Chambers (1991) who identify a lack of uniformity in interpretations of the meaning of flexibility in manufacturing industry.

Other researchers identify the need to measure flexibility, for example Kaplan (1990) identifies flexibility along with quality, delivery times and suitable operational measures to allow managers to control their managerial functions. Naik and Chakravarty (1992) quote flexibility amongst other long term strategic benefits, as difficult to quantify. Kaplan (1990) cites a number of case studies illustrating good practice using these operational measures, but none of the case studies actually measure flexibility. Instead they focus on the easier to measure quality and delivery times.

Industrialists therefore need to have a clear concept of what needs achieving before they can take logical steps to achieve it.

In order to improve understanding researchers defined different types or typologies of flexibility. Also to justify and manage projects where flexibility is quoted as a major benefit, there exists a need to quantify flexibility (Lenz, 1992 and Blackburn and Millen, 1986). It is acknowledged, however, by Parkinson and Avlonitis (1982) that some of the benefits that accrue from flexibility are intangible and difficult to evaluate.

1.5 Aims and Objectives

In Section 1.4 the need to measure flexibility is highlighted. Quantifying flexibility in terms of its value to the company, allows investment to improve flexibility. This section will outline the requirements of such a measuring system, which will form the aims and objectives for the thesis.

The aim of the thesis is to develop measures for flexibility which can easily be used in a manufacturing environment. Shown below are specific objectives that allow this aim to be achieved:

1. The data for input values must be easy to obtain.

For example numbers of machines rather than an abstract notion such as the concept of machine interaction (Roll, Karni and Arzi, 1990).

2. Outputs must be meaningful.

The outputs must relate to the existing theory and preferably relate to existing types of flexibility previously defined in the literature.

3. Methodology must be easy to use.

Uses a technique which is familiar to most manufacturing engineers

4. Must be cheap.

Minimises use of expensive specialist hardware or software such as a manufacturing simulator

5. Be able to assess flexibility across a range of industries.

Is relevant to different types of production such as batch, continuous.

The major requirements of any measuring system for industrial use are that it should be easy to use and have a relevant output. For the output of a flexibility measuring system to be relevant, it should be theoretically sound and it has to be focused on a particular type of flexibility. The type of flexibility can be defined by the designer of the measuring system or preferably, relate to one of the existing flexibility types. To meet this requirement, this thesis examines Product and Mix Flexibility as defined by Slack (1990). Product and Mix Flexibility were specifically chosen because they relate to the product range offered by the company and are therefore are among the principle types of flexibility through which the customer perceives flexibility in the manufacturer. It is also important that the measurement method be useable across a range of industries as flexibility, as highlighted in section 1.1, is relevant to many different sectors.

The ease of use is dependent on the inputs required by the measurement system, the cost of the system and the tools it requires. The inputs to the system should be easily quantified by the user. The methodology of the measuring system should be easy to use, and employ a technique familiar to most industrialists. Also the methodology should also not require tools that are not usually available to most companies.

1.6 Summary of Thesis

Chapter 2 is the first of three literature survey chapters. It considers different types of manufacturing systems in terms of flexibility. Methods of controlling manufacturing systems are examined in terms of their impact on the flexibility of the manufacturing system. The chapter further considers some of the methods that have been developed to achieve flexibility or minimise the need for flexibility.

Chapter 3 examines how manufacturing strategy relates to flexibility. It identifies flexibility as an important performance metric within manufacturing strategy and identifies that flexibility should be used in a focused manner rather than indiscriminately. Typologies, the frameworks which define different types of flexibility, are discussed and the two dimensional nature of flexibility is considered. Internal flexibility and external flexibility are identified and time scales for change are outlined.

Chapter 4, the final literature survey chapter, considers the quantitative aspects of flexibility research. A number of numerical approaches to measuring flexibility are identified and their disadvantages highlighted. Flexibility is also considered in the context of financial evaluation and finally a number of flexibility modelling techniques are explored.

Chapter 5 outlines a methodology for measuring flexibility and develops a conceptual model that represents the basis of this methodology. It simplifies an initially proposed model to allow practical use. The model is then interpreted and methods for numerical evaluation are identified. These methods allow measurement of product and mix flexibility.

Chapter 6 considers measurement of product flexibility. A three dimensional database is outlined and a method for numerical interpretation is identified. Examples are provided to illustrate aspects of the measurement method.

Chapter 7 develops a method for measuring mix flexibility. The method is based on the theoretical model proposed by Chyssolouris and Lee (1992) but applies the model to measure mix response flexibility. The method developed is tested using three different theoretical manufacturing systems and validated against simulation data.

Chapter 8 applies the methodology developed in Chapters 5,6 and 7 in two contrasting companies. One company Bostik Ltd processes chemicals, the other Richard Kimbell Ltd. manufactures wooden furniture.

Chapter 9 discusses the research methodology and explores issues related to the application of the flexibility measurement method developed. The results from the case studies are discussed and interpreted, providing an illustration of how the measurement method can be generically applied.

Chapter 10 compares the aims identified in Section 1.5 with the work achieved and concludes that the methodology is usable in a manufacturing environment and applicable across a range of industries.

2. FLEXIBILITY AND MANUFACTURING SYSTEMS

This chapter considers flexibility in relation to types of manufacturing systems. This includes different types of layout and methods of controlling manufacturing systems including scheduling and stock control. The final section looks at methods that have been developed to achieve flexibility or to minimise the need for flexibility.

2.1 Manufacturing Layouts

2.1.1 Fixed Position Layouts

The fixed position layout is the most traditional of all types of layout. The product stays in a fixed position and machines and operators move to the product. Today this type of layout is used for construction and other large scale projects. It is generally used for 'one off' type production and is comparatively expensive.

In terms of flexibility, this type of layout is generally considered to be the most flexible (Black, 1983). On closer examination, however, it can be seen that fixed layouts do have limitations to their flexibility. They can potentially make a wide range of products but their response in changing from product to product is slow.

2.1.2 Process or Functional Layouts

Process layouts focus their design around the different processes required to manufacture a range of products. Machines that fulfil the same function or perform the same process are grouped together. Products move from functional group to functional group according to their process requirements.

This type of layout is generally used where flexibility is needed in the range of products and a moderate quantity of product is required. It is generally considered to be the most common type of layout for flexibility of product range, within a mass manufacture environment (Gupta and Goyal 1989). Process layouts also have additional flexibility in terms of being able to manufacture a number of different products at the same time, providing there is no conflict between processing requirements of products.

2.1.3 Product Layout

Product layouts are generally used in high volume manufacture. The factory is designed around the manufacture of a single or range of similar products. The machinery in this type of layout is often specifically designed for the manufacture of the product, and uses a high degree of automation.

Flexibility in terms of the range of products manufactured is very limited (Gupta and Goyal 1989). If a manufacturer wishes to produce another product, it will often be necessary to build a new line. However, if a line is capable of manufacturing more than one product the change over between products can be fast.

2.1.4 Cellular Manufacture

Cellular manufacturing (C.M.) started to be more widely adopted in the early 1980's (Stevenson 1993). The drive for C.M. was caused by the need to manufacture a wider variety of products cheaply. Cellular manufacture tends to fit between process and product layouts in terms of volume and variety of product as shown in Figure 2.1. It works by grouping products or components by process requirements, such that a simple manufacturing cell that meets all the manufacturing requirements of those products or components can be designed. A factory would consist of a number of different cells which service different product groups.

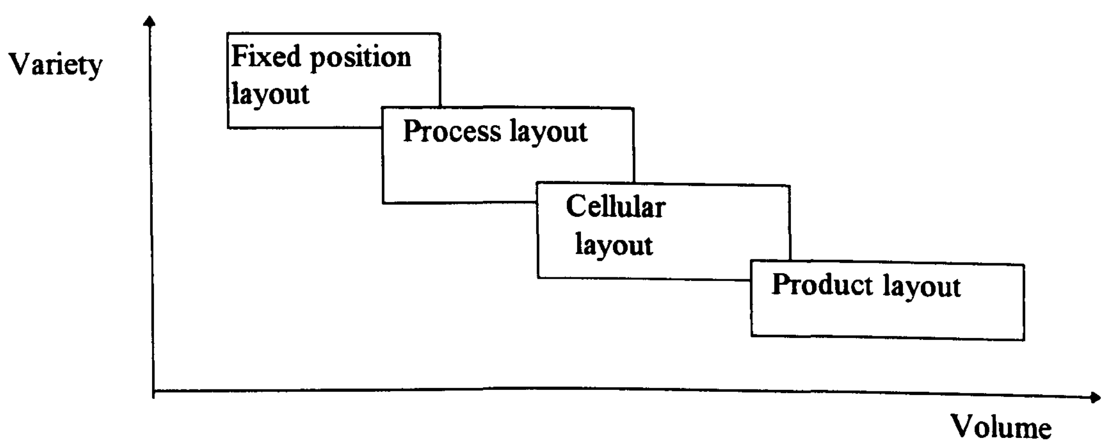


Figure 2.1: Volume vs Variety for Manufacturing Systems

Cellular manufacture tends to improve the overall flexibility of the manufacturing system (Bateman and Stockton, 1993). This is because each cell can focus on the type of flexibility that is important to its group of products; there is no need to dilute effort to cater for process variety that is outside the needs of the group of products assigned to the cell. This means that the manufacturing system as a whole aggregates the flexibilities of the separate cells to provide a portfolio of different types of flexibility, focused as required by product groups.

2.2 Manufacturing Systems and Control

Value adding activities in manufacturing take place on the shopfloor, and require to function effectively, control systems to manage these activities. To respond to changing product and volume demands there is a need for the systems that control the shopfloor to have flexibility (Bauer 1995). Bauer (1995) recognised these needs and stated that flexibility can be achieved through reconfiguring control systems software. He suggested an economic way of achieving this through the use of software modules that can be re-used.

Slack and Correa (1992) took a more general approach and discusses what they termed infra-structural flexibility, which is defined as '*the systems, procedures and practices which bind the manufacturing operation together*'. This can be considered to include shopfloor management and control systems.

Slack and Correa (1992) examined two manufacturing plants: Plant A which was run using a JIT system and Plant B which was run using an MRP system. Broadly, Plant A had the capability to respond quickly to changes but only within prescribed limits. The limitations on flexibility in Plant A tended to derive from JIT's philosophy of stability. Plant B could not respond as quickly as Plant A but could respond to a greater degree. The reasons for this were two fold, firstly company B was experienced in changing the product range as designs were often modified and secondly an MRP system is not subject to the philosophical stability of JIT. The limits to flexibility of Plant B tended to stem from the technological limitations of MRP such as the need for high data integrity.

Muramatsu, Ishii and Takahashi (1985) analyse the flexibility of push and pull systems more numerically. They analysed the two types of system with regard to how they each coped with variations in order quantity. They measured the degree of amplification of variations in order quantity, where amplification is defined as an over response to an increase in orders of a product, for example if the number ordered of product A is increased by 10 units the order processing system may order 12 of each of the components. In turn the raw materials to make these components is increased to make an additional 14 of each of the components. Thus amplification is an undesirable feature of manufacturing control systems. The findings illustrate that, as might be expected, pull systems exhibit a lower level of amplification compared to push systems, such as MRP It is the hierarchical nature of MRP that uses bills of materials and master production schedules to determine demand, combined with specific lot sizes that would tend to amplify variations in demand.

Nakha (1995) discusses the need for scheduling flexibility particularly in the food industry where cross contamination of flavours and the strict hygiene rules impose rigorous requirements on the schedule of products. He proposed that conventional methods of scheduling are not appropriate to this environment and outlined a new method that allows operators scheduling flexibility despite the limitations imposed by cross contamination. He suggested that for a yoghurt production process three types of manufacturing system are used. The first type is a continuous flow with a dedicated line for each product. The second, uses a fixed sequence of products, which avoids cross-contamination and minimises wash-outs. Here flexibility is achieved by varying the volumes manufactured of each product and omitting products in the sequence if necessary. The third type deals with low volume products and requires intelligent application of cross contamination rules and generally results in more wash-outs than the second type.

2.3 Methods of Achieving or Coping with the Need for Flexibility

An alternative to possessing flexibility in a manufacturing system is to reduce the need for flexibility. This approach has been identified by Fisher, Hamman, Obermeyer and Hammond (1994) and Mather (1995). Mather discusses the variability of demand in business and identifies the cost and disruptive effects of this on the manufacturing system. He proposes that a number of practices in companies actually cause additional variability in demand. Examples of these practices include:

1. Sales promotions during periods of existing demand - this creates demand during periods which already run the factory at peak volume.

2. Price increases which are flagged to the customer before they occur - customers understandably want to place their orders before the price increase.

3. Periodic sales targets - sales staff are encouraged to increase the number of orders placed as deadlines approach.

4. Calendar fixed payment dates - customers will use this to exploit credit terms, for example if payment dates are on the 15th and 29th of each month they will place orders on the 16th and 30th.

5. Inventory replenishment systems - this forces customers to order in fixed batch sizes. This will tend to over stock their stores in one period, and thus in successive periods they will order less.

Mather proposes a number of solutions to eliminate these erroneous peaks in demand.

A more sophisticated approach is taken by Fisheret al. (1994) who investigate the variations in demand of seasonal products such as ski clothing. Inaccurate forecasts in the fashion business are particularly expensive because products rapidly become obsolete. This costs the company both in terms of having to discount unwanted items and loss of income through not being able to meet demand. To reduce these costs the authors try to reduce variation in demand, but acknowledge that there will always be variation in seasonal products such as ski wear. This will inevitably put pressure on the manufacturing system. To reduce this pressure they adopted a two stage approach:

The first stage is to even out demand by making to stock and using common components such as same colour zippers. The second stage is to identify those products that are likely to have a predictable demand and assign those products to be made to stock. Other products that have more prediction risk associated with them, will be made in response to demand as it occurs. This approach is compatible with the concept of focused flexibility outlined in Section 3.1.3. A company could focus the flexibility of their manufacturing system on those products that are identified as requiring flexibility; other products that are more predictable can be aggregated to a more stable overall demand.

The use of computerised technology and particularly FMS have been associated with the provision of flexibility (Harvey and Page 1986) as identified in Section 1.3. Computerised technology yields benefits over hard wired automation in a number of different ways. The most obvious is the ability to rapidly download programs from a storage medium such as hard or floppy disk. This enables the instructions to manufacture a different product to be readily available, thus reducing change-over times (Kellock 1985).

Tidd (1991) reviews the impact of technology on issues associated with flexibility. In his chapter on manufacturing strategy and technological divergence he compares the experience of Japan and the UK. Japan has a higher population of robots than the UK as shown in Table 2-1.

	UK	Japan
Number of robots	3	15
Most common type of robot	Articulated	SCARA
System configuration	Cell	Line
Annual production volume	250,000	1,000,000
Number of product variants	6	15
Product life cycle (years)	7	4

Table 2-1: Typical Characteristics of Robotic Assembly Systems in the UK and Japan (Tidd, 1988)

Despite the higher sophistication of the UK robots it can be seen that the Japanese robots exhibit higher flexibility, in that they can cope with more product variants and product introductions.

Tidd explains this apparent contradiction by stating that " *Clearly technology has not been the most significant factor*" in achieving flexibility but "*organisational context has strongly influenced development and adoption of the technology which has in turn affected manufacturing flexibility*"

An alternative to achieving flexibility through computerised technology, has been suggested by Owen, McIntosh, Mileham, Culley, and Gest (1995), who proposed the use of excess capacity to increase the ability to change between products. They proposed using parallel machines where long set-up times inhibit product changes. Having parallel machines allows all set-ups to be "external" (Shingo 1985) i.e. all set-ups occur off line on the excess machine, whilst the other machine is in use for production. Using this method there is no penalty in lost production time due to changing product. Owen at al. acknowledge this could be an excessively expensive approach, and advise the judicial use of this technique, only where excess machines are available.

3. MANUFACTURING STRATEGY AND TYPES OF FLEXIBILITY

Researchers into manufacturing flexibility have taken a number of different approaches, which can be divided into three areas: strategic, qualitative and quantitative. The strategic work outlines the role flexibility should take within a manufacturing strategy and highlights the need for flexibility as part of an overall strategy. The qualitative work attempts to further reveal the nature of flexibility. It consists of defining flexibility into types and examining the need for flexibility over different time scales. This chapter considers the qualitative and strategic aspects of this research.

3.1 Manufacturing Strategy And Performance Measures

Porter (1985) defines competitive business (or corporate) strategy as:

> "The search for a favourable competitive position in an industry, the fundamental arena in which competition occurs. Competitive strategy aims to establish a profitable and sustainable position against the forces that determine industry competition"

Manufacturing strategy is related to business strategy in that manufacturing strategy's purpose is to focus the manufacturing function to facilitate the business strategy and thereby improve competitiveness. This is demonstrated by Leong, Sydner and Ward (1990) who illustrate the relationships between business strategy, manufacturing strategy and competitive priorities in Figure 3.1. Decision areas relate to the long term performance of the manufacturing system. Competitive priorities are the elements of the business goals that have been translated into manufacturing decisions.

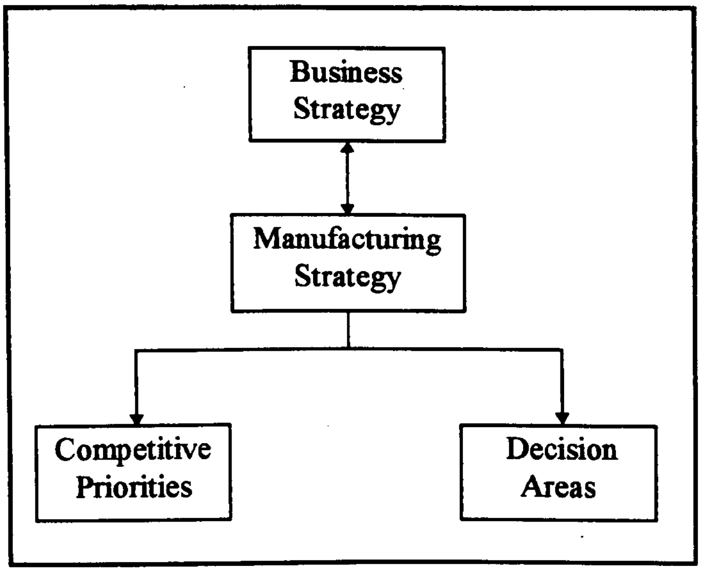


Figure 3.1 Predominant Model of Manufacturing Strategy Leong et al. (1990)

Specific competitive priorities are identified by Chambers (1992) in his formulation of manufacturing strategy. Outlined in Table 3-1 is a five stage framework for the formulation of manufacturing strategy. Step 3 identifies a number of competitive priorities including several that are related to flexibility, such as colour and product range. This shows how flexibility can support the corporate objectives identified in step 1.

Table 3-1: Five Step Manufacturing Strategy Framework (Chambers 1992)

			Manufacturing Strategy	
Corporate objectives **Step 1**	Marketing Strategy **Step 2**	How do products win orders in the market place? **Step 3**	Process Choice **Step 4**	Infrastructure **Step 5**
• Growth, Survival, • Profit, • ROI, • Others	• Product markets and segments • Range • Mix • Volumes • Standardisation/ customisation • Level of innovation • Leader/follower	• Price • Quality • Delivery speed / reliability • Demand increases • Colour range • Product range • Design leadership • Technical support	• Choice of processes • Trade-offs in process choice • Process positioning • Capacity size timing, location • Role of inventory	• Function support • Planning control systems • QA/QC • Procedures • Payment system • Work structuring • Organisatio nal structure

3.1.1 Flexibility as a Performance Measure

Flexibility is identified by Leong et al. (1990) as a competitive priority along with quality, cost and delivery performance. As a competitive priority, flexibility can be generally considered to be one of the measures of performance of a manufacturing strategy. This is specifically mentioned by Voss (1995) who identifies flexibility as one of the "*statements of the competitive dimensions of manufacturing*". This is also reflected by Wainwright (1993) who summarises ten manufacturing strategy frameworks in Table 3-2. It can be seen that eight of the frameworks identify flexibility as a performance criterion.

Table 3-2 : Comparison between Manufacturing Strategy Frameworks (Wainright 1993)

		SKINNER	WHEELWRIGHT	HAYES AND WHEELWRIGHT	FINE AND HAX	BUFFA
DECISION AREAS	Structural	• Plant and equipment	• Capacity • Facilities • Technology • Vertical Integration	• Capacity • Facilities • Technology • Vertical Integration	• Capacity • Facilities • Technology • Vertical Integration	• Capacity location • Facilities • Technology • Vertical Integration
	Infra Structural	• Production planning and control • Labour and staffing • Organisation and management • Product design / engineering	• Production planning and control • Workforce • Quality control	• Production planning and control • Workforce • Quality	• Human resources • Quality management • New products	• Operational decisions • Workforce
Performance Criteria		• Efficiency • Quality • Delivery • Flexibility	• Efficiency • Dependability • Delivery • Flexibility	• Cost • Dependability • Delivery • Flexibility	• Cost • Quality • Delivery • Flexibility	• Cost • Dependability • Quality • Flexibility

Table 3-2 continued :Comparison between Manufacturing Strategy Frameworks (Wainright 1993)

		COHEN AND LEE	GUNDASON AND RIIS	HILL	HAAS	BECKMAN *et al*
DECISION AREAS	Structural	• Capacity • Facilities • Plant layout	• Technology • Plant layout	• Technology	• Technology • Supplier roles	• Capacity • Facilities • Technology • Vertical Integration
	Infra Structural	• Control organisation • Product quality	• Production planning and control • Organisation and management	• Controls and procedures • Organisation	• Human resources • Organisation	• Workforce • Quality • Organisation • Information systems
Performance Criteria		• Cost	• Delivery	• Price	• Price	• Cost
		• Service	• Features	• Delivery	• Service	• Quality
		• Quality	• Flexibility	• Reliability	• Quality	• Flexibility
		• Flexibility		• Quality		• Features

It has been argued by Primrose and Verter (1996) that there is no need to define or measure flexibility. They state that all aspects of flexibility can be measured by other means such as improvements in delivery performance. Primrose and Verter do not, however, discount the value of flexibility as they go on to conclude that "*Manufacturing facilities must have sufficient capability to cope with change and uncertainty*".

To avoid the need to measure flexibility directly, Primrose and Verter suggest that manufacturers should assess whether their manufacturing system is capable of dealing with the uncertainty that is forecast. This should certainly assist in the selection of systems but does not provide an indication of the degree of ability to cope with change. The development of a measure of flexibility will provide this degree of ability to cope, and so enhance decision making.

Maskell (1989) in his paper on performance measurement for World Class Manufacturing (WCM), specifically identified flexibility as an important performance measure along with, quality and work force management measures. He further identified seven common characteristics for performance measures in WCM companies i.e.

1. Directly related to manufacturing strategy
2. Non-financial
3. Vary between locations
4. Change over time
5. Simple and easy to use

6. **Fast feed back**
7. **Intended to teach rather than to monitor**

Flexibility as a performance measure exhibits the first two of these characteristics: the link between flexibility and manufacturing strategy is clearly shown in Table 3-2 and flexibility is generally a non-financial measure. The remainder of the characteristics could apply to a measure of flexibility but largely depend on how the measure is designed, and thus should be considered at the design stage of a flexibility measurement system.

Flexibility is also important as a day to day measure; it has been shown that managers adapt their actions to the measures that are made of their departments performance (Neely, Mills, Platts, Gregory and Richards,1994). A typical example is cost accounting, which is a strong driver for managerial behaviour. It has become evident that traditional cost accounting methods are suppressing activities that are now deemed desirable. Kaplan (1990) in his chapter on the limitations of cost accounting, outlines a number of case studies in which traditional cost accounting measures such as machine efficiency and labour variances inhibit attempts to improve quality and flexibility. He suggests that cost accounting still has a role to play in measuring performance but should be modified to reflect modern manufacturing practices and be part of a suite of other operational measures, which should include flexibility.

3.1.2 Focused Flexibility

It could be considered that flexibility undermines the need for a manufacturing strategy i.e. if the manufacturing function is totally flexible it would negate the need for the focus that manufacturing strategy brings. However, Hill (1985) and Slack (1990) identify that having a *totally* flexible manufacturing system is not practical. As Slack states "*Any operation which is flexible enough to fit in with strategic direction no matter what it is, at best will be using its capabilities in a hopelessly ineffective manner*". In order to avoid this, it is suggested by Slack (1990) and Hill (1985) that flexibility be used in a focused manner to support the manufacturing strategy. This avoids wasting flexibility effort to support inadequacies in the manufacturing function or trying to fulfil flexibilities that are not important to the market. This approach accords with Skinner's (1974) general statement on performance measures "*a factory cannot perform well on every yardstick*" if it is considered that different types of flexibility represent different yardsticks.

Examples of how flexibility can help specific areas of competitiveness are outlined by Kim (1991) and Hayes and Wheelwright (1984). Kim (1991) identifies a number of ways in which types of flexibility can help support competitive priorities, such as dependable deliveries and fast delivery. Hayes and Wheelwright (1984) state that flexibility can be used explicitly as a competitive tool, for example through broad product lines and rapid design changes. Thus as Hill (1985) states "flexibility as panacea" should be replaced by the concept of "what level and type of flexibility do we require?" in order to fully exploit the potential of flexibility as a competitive tool.

Adler (1988) also supports this view of focused flexibility, and goes further to suggest that in order to fully utilise aspects of flexibility, a backdrop of stability is required. He argues that managing flexibility takes a great deal of management effort and so is expensive. Thus, in order not to waste management effort, it is important to find those aspects of the business that should be flexible and those that should be stable.

3.2 Qualitative Research

The general theme of the qualitative research is to explore the nature of flexibility. This consists of authors outlining a flexibility typology. Flexibility typologies have been further elaborated by the consensus among researchers that each type of flexibility has two dimensions; range and response. Qualitative research also has looked at internal and external flexibility, terms that shall be examined later in this section.

3.2.1 Typologies

The purpose of a flexibility typology is to divide flexibility into types that can be considered separately. This enables the designer of a manufacturing system to incorporate those flexibilities that are considered important to the manufacturer and ignore those which are not. Typologies also allow the people concerned with flexibility, a framework within which they can communicate, i.e. to specify what type of flexibility they mean rather than just "flexibility". Thus it is possible, as recommended in Section 3.1.2, to specify more clearly on which type of flexibility effort should be focused.

Examples of two typologies are Browne, Dubois, Rathmill, Sethi and Stecke (1984) and Slack's (1990) which are shown below in Table 3-3 and Table 3- 4 respectively.

Table 3-3 : Browne et al's (1984) Flexibility Types

Flexibility type	Definition
Machine	The ease of changing between a given set of parts: for example the set up time required to change manufacture from one part to another.
Process	The range of parts that the manufacturing system can produce.
Product	The ability to change the given set of parts: i.e. the ability to incorporate new designs of product in the manufacturing system.
Routing	The ability to handle breakdowns and continue manufacture.
Volume	The ability to operate profitably at different volumes.
Expansion	The capability to expand as needed.
Operation	The ability to change the ordering of several operations required to manufacture a part.
Production	The universe of products that can be produced

The typology outlined in Table 3-3 was originally conceived for FMS's, however, it can be applied to other common manufacturing systems such as job shops, flow lines and to some extent the process industries.

Browne further stated that these types of flexibility are to some extent dependent on each other. That is, one type of flexibility may contribute to the flexibility of another type. The hierarchy of the different types of Browne's flexibilities is shown in Figure 3.2.

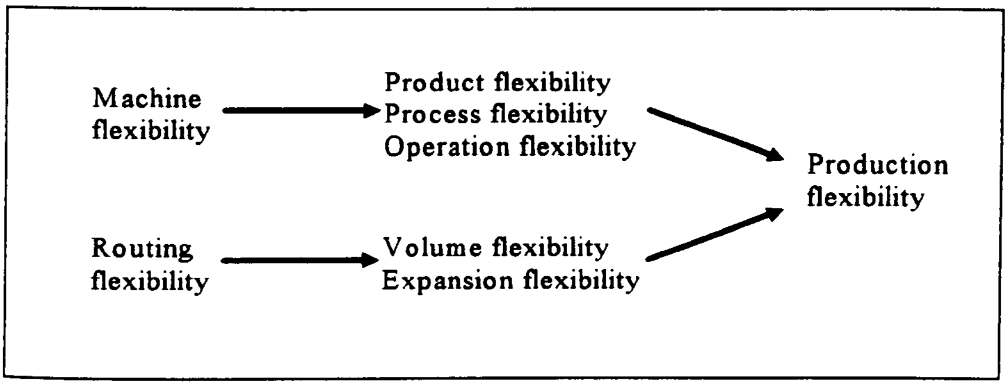


Figure 3.2: Relationships between Flexibility Types, Browne et al. (1984)

Slack's (1990) typology (Table 3-4) consists of four main areas; volume, delivery, product and mix. Each of these is expressed in terms of:

a. range - i.e. how much flexibility; and

b. response - i.e., how easily the flexibility can be achieved

Response can be considered in two ways, either as a response time, or the effort required to respond to a change. Response time can be simply measured in terms of its duration , but effort may be measured in terms of other resources such as finance or labour.

Table 3-4: Slack's (1990) Flexibility Types

Flexibility type	Range	Response
Mix	The range of products a company can currently manufacture	How quickly the company can change between manufacturing different current products
Product	The range of products the company could produce	How quickly new products could be introduced
Volume	The output range over which the company can economically manufacture	How quickly the output can be changed
Delivery	The range over which delivery times can be altered	How quickly delivery times can be altered

Comparing Slack's and Browne's typologies it is evident that Slack's is a simpler typology because it has fewer types. This simplicity has two effects: firstly Slack's is a more robust definition and so may be applied to business functions other than manufacturing, and secondly it only considers the operational system from the outside, i.e. events that occur inside the operational system such as breakdowns are not considered. Browne's typology, however, does consider internal change by using routing flexibility, which expresses the changes that take place *within* the manufacturing system. This can be related to internal and external change, which is further discussed below.

The other main difference between Browne's and Slack's typologies is the two dimensional nature of Slack's typology, i.e. each flexibility type can be expressed in terms of range and response. If Browne's flexibility types are examined, it can be seen that they do incorporate concepts of range and response, but in a less comprehensive way than Slack's. For example, machine flexibility is largely a response flexibility and Browne proposes that it be measured in terms of time and process flexibility is a range flexibility and should be measured in terms of the number of parts to be manufactured. Slack's explicit use of range and response is a more lucid approach that is supported by other researchers in the field, for example Crowe (1992) stated "*At a minimum, appropriate measures of flexibility must evaluate diversity and time*".

Although range and response are generally considered to be independent variables, a relationship can exist: if response is considered over a sufficient length of time then any range can be achieved given enough resources. However, this would involve changing the manufacturing system beyond its current commercial purpose. Thus strictly a system's range flexibility is dependent on response flexibility. However, they can be considered independent if a realistic time frame is considered.

The typologies outlined above are two examples of many (Sethi and Sethi 1990). Other typologies express similar concepts and so it is considered that these two examples give a good overview of the research available.

3.2.2 Internal And External Flexibility

Buzacott (1982) stated that there are internal changes and external changes to manufacturing systems. Internal changes are changes within the manufacturing system such as machine breakdowns, and external changes are changes to the output of the manufacturing system such as producing a different product range. Buzacott

(1982) further cited Mandelbaum's definition of action flexibility and state flexibility that related them to internal and external flexibility. Action flexibility is the ability to change the outputs of the manufacturing system and can be considered to be external flexibility. State flexibility is the ability to deal with internal changes and changes to the inputs of the manufacturing system, and still continue to output the same product. State flexibility can also be thought of as system robustness which Correa (1992) outlines and proposes as an addition to Slack's (1990) typology of mix, product, volume and delivery flexibilities

The concept of external flexibility is further considered by Swamidas and Newell (1987) who state that manufacturing flexibility helps companies deal successfully with changing environmental uncertainty. They demonstrate this by showing that companies with higher flexibilities performed better in areas such as sales growth and growth in total assets.

3.2.3 Time Scales

Carter (1986), Gustavsson (1984) and Gupta and Buzacott (1989) have used time scales as a method of classifying flexibility. Gustavsson identifies various problems that are associated with specific time scales. These problems are incentives for having flexibility. He identifies these as:

a. Short term operational problems e.g. replanning due to breakdowns.

b. Medium term tactical problems e.g. changes in design.

c. Long term strategic problems e.g. investments in expansion.

These problems are then related to three main areas where a company would require flexibility i.e. changes in the product, changes in the production system and changes in demand. Gustavsson concludes that to achieve flexibility effectively there is need for some standardisation. This mix of flexibility in a context of standardisation is similar to that of Adler's (1988) mix of flexibility and stability.

Carter considers that different types of flexibility impact on the manufacturing system over different time frames. Carter identifies four time frames over which flexibility should be considered i.e.

a. Very Short Term: One to three days, e.g. delivery schedules.

b. Short Term: One to two months, e.g. engineering changes lead times.

c. Medium term: Six months to two years, e.g. new product design.

d. Long Term: Five or more years, e.g. time to develop new markets.

Carter states that driving the need for each of these flexibilities, are one or more of the three incentives shown below:

Insurance	: Protection against uncontrollable variables
Economics	: The most economic method of production
Strategy	: Manifestation of business strategy

For instance, expansion flexibility (as defined by Browne et al. 1984), is identified as a medium to long term time frame and driven by strategic incentives.

Gupta and Buzacott (1989) considered Carter's (1986) and Gustavsson's (1984) work and concluded that it is better to consider *changes* over the three time scales (short, medium and long) rather than *flexibility* over different time scales (as in Carter's work).

3.3 Summary

Flexibility has been identified as an important performance criterion, particularly as part of manufacturing strategy. In order to effectively utilise flexibility it should be focused in areas that are of importance to the market. This avoids wasting effort in obtaining flexibility where it is not required.

Examining the nature of flexibility it has been acknowledged that it has different types, and each type has two dimensions, range and response. Flexibility types can also be described as internal, which aids system robustness, or external that allows change in outputs. In terms of analysing flexibility it is also useful to consider flexibility over a range of time scales.

4. MODELLING AND QUANTITATIVE RESEARCH

This chapter considers the different approaches that researchers have taken to evaluating flexibility. These approaches stem from diverse areas of research such as information theory, probability, set theory and entropy. A number of different methods for evaluating flexibility are considered: numerical values for flexibility; indirect measures of flexibility; financial evaluation and justification of flexibility; and modelling flexibility.

4.1 Numerical Evaluation of Flexibility

Many approaches to the numerical evaluation of flexibility have been documented. Outlined below are a representative sample of the methods that have been proposed. The rigour with which these measures have been developed, the degree to which they accord with the typologies identified in chapter 2, and their practical implementation are examined.

Roll, Karni and Arzi (1990) concentrate on routing flexibility as defined by Browne et.al. (1984). This measure they define as F_1., which is calculated as shown in Equation 4.1

$$F_1 = \left[\frac{M_0 / N_0}{M^{1+\alpha}} \sum_J S_J^{\alpha} \right]^{\beta} \qquad \text{Equation 4-1}$$

Where :

M = number of machines in a cell

M_0 = number of machines in the bottleneck area,

N_0 = number of operations performed in the bottleneck area,

S_j = no of machines out of M that can do operation j,

α = The marginal effect of adding extra machines, and

β = Interactivity between two elements A_1 and B_1,.

The measure for F_1 is developed from the product of two elements, A_1 and B_1 raised to the power β. Thus:

$$F_1 = (A_1 B_1)^{\beta} \qquad \text{Equation 4-2}$$

Where A_1 represents a measure of flexibility, which relates the number of machines M to S_j, the number of machines that can perform operation j and β is a parameter that takes into account the interaction between A and B. Thus at maximum flexibility S_j=M, i.e. all machines can perform any operation. Hence, flexibility can be expressed as the proportion of machines that can perform each operation. Mathematically this can be expressed as:

$$A_1 = \frac{1}{N}\sum_j \left[\frac{S_j}{M}\right]^{\alpha} = \frac{1}{NM^{\alpha}}\sum_j S_j^{\alpha} \qquad \text{Equation 4-3}$$

Where:

$\alpha < 1$.

N = number of operations in cell

The purpose of α is to reflect non-linear, marginal effect of adding additional machines. Thus there is a necessity to raise S_j/M to the power of α.

Flexibility will not be the same throughout the manufacturing system. Hence, it is important to find the limiting factor on flexibility. This will be a "bottleneck" area, so to highlight the limiting factor on flexibility the additional parameter B_1 is introduced.

$$B_1 = \frac{N/M}{N_0/M_0} \qquad \text{Equation 4-4}$$

Where:

N_0 = the number of operations associated with a bottleneck,

M_0= the number of machines associated with a bottleneck.

In order to use the formula for flexibility derived , it is necessary to evaluate α and β. This could represent a problem, as neither of the values of these parameters is evident immediately from a manufacturing system. This measure does however have the advantage of being defined in terms of an established typology.

Kumar (1987) takes an information theory approach. He adapts the concept of entropy from its most common interpretation of disorder in a system, to represent a measure of uncertainty. He then relates uncertainty i.e. a possible number of outcomes, as the flexibility in a system. He goes on to identify a number of essential axioms and desirable axioms for such a measure of flexibility. These are principally related to ease of analysis rather than what would clearly represent flexibility in manufacturing systems. Kumar then assesses a number of known measures of entropy against the desirable and essential axioms.

These concepts are developed by Gupta and Gupta (1991). who expand the most sophisticated measure proposed by Kumar and apply it to a number of simple examples. These examples look at the probability that a cell will be available for processing a component. They use a measure S of entropy and equate it to flexibility. This is developed into a function for S expressed in terms of the probability of machine cells being available. The case outlined below is for two cells and one component.

$$S = \frac{1}{1-\beta}\int_0^1 \ln\left[\frac{\left[\alpha f(\alpha)^{\gamma+\beta-1}\right]+\left[(1-\alpha)f(\alpha)\right]^{\gamma+\beta-1}}{\left[\alpha f(\alpha)\right]^{\gamma}+\left[(1-\alpha)f(\alpha)\right]^{\gamma}}\right] \qquad \text{Equation 4-6}$$

Where:

α = the probability of a cell being available. It is assumed that α, the probability of a cell being available is the same as the probability of the component visiting that cell.

$f(\alpha)$ = the density function of α and

β and γ are parameters whose values are dependent on the type of manufacturing system being modelled.

Gupta and Gupta (1991) explore a method for maximising S for different distributions $f(\alpha)$ subject to the constraint shown in Equation 4-7

$$\int_0^1 f(\alpha)d\alpha = 1 \qquad \text{Equation 4-7}$$

Using Lagrangian multipliers, a function for $f(\alpha)$ can be calculated in terms of α, β, γ and λ (where λ is the Lagrangian multiplier) as shown in Equation 4.8

$$f(\alpha) = e^{-\lambda}\left[\frac{a^{\gamma+\beta-1} + (1-\alpha)^{\gamma+\beta-1}}{\alpha^{\gamma} + (1-\alpha)^{\gamma}}\right]^{1/(1-\beta)} \qquad \text{Equation 4-8}$$

It is shown that as β and λ vary, the maximum value for $f(\alpha)$ remains at $\alpha = 0.5$. Thus proving for maximum flexibility for a two cell, one component model, there should be an equal probability, of using each cell. The paper develops similar sets of equations for different numbers of cell and components. There are a number of problems associated with this method i.e.

1. The values of β and λ are not known- Gupta and Gupta state that they depend on the type of manufacturing system and the maintenance policies employed.
2. Each different system modelled requires new and complex equations to be developed from first principles.
3. There is an assumption that α the probability of a cell being available is the same as the probability of the component visiting that cell, this has not been demonstrated in the paper.
4. The type of flexibility being measured is not defined.

Chryssolouris and Lee (1992) have acknowledged some of these above problems. They develop equations for two specific types of flexibility, operational flexibility and product flexibility, as defined by Browne et al. (1984). Their models are based on the concept that a measure of flexibility should take into account the difficulty of changing, or as described in the paper, the penalty and the probability of that change occurring. The paper defines flexibility as being inversely proportional to sensitivity to change ($\dot{S}TC$) i.e

$$\text{Flexibility} = \frac{1}{STC} \qquad \text{Equation.4-9}$$

STC is defined as:

$$STC = Penalty \times Probability\ of\ occurrence \qquad \text{Equation 4-10}$$

For the variety of potential changes that are possible within a manufacturing system, this can be formalised to:

$$STC = \sum_{i=1}^{n} Pn(X_i)\Pr(X_i) \qquad \text{Equation 4-11}$$

Where:

n = the number of potential changes,

i = the state or change transition index,

X_i = the ith potential change and

$Pn(X_i)$ = the penalty of the ith potential change.

$Pr(X_i)$ = the probability of the ith potential change

Chryssolouris and Lee developed these equations to calculate the product flexibility and operational flexibility of a number of manufacturing systems and used them to compare different types of manufacturing system. The models successfully identified the system that has least cost for a number of potential product introductions and the least cost for a range of levels of volume expansion.

This method has the advantage of being fairly simple, the values of the variables are quantifiable and the measure is related to specific types of flexibility.

The methods outlined in this section have a common application of providing a numerical assessment of flexibility. These methods, however, are not without problems. For the methods outlined by Roll et al. (1990) and Gupta and Gupta (1991) it is difficult to evaluate all the parameters required by the equations and it is not obvious where to apply them. Some of the mathematics required to develop the equations for specific cases in Gupta and Gupta (1991) are complex and difficult to use. These factors are likely to inhibit their general application in manufacturing.

Both Roll et al. (1990) and Chryssolouris and Lee (1992) relate their flexibility measure to specific types of flexibility. This is important because a single measure of flexibility would not be able to assess different types of flexibility.

4.2 Indirect Measures of Flexibility

An alternative approach to developing a direct numerical measure of flexibility as outlined in Section 4.1, is to measure the benefits accrued from flexibility. This approach has been used and supported by Primrose and Verter(1996) and Byrne (1992).

Primrose and Leonard (1984) examine the performance of different types of FMS. The paper considers three levels of automation, CNC machines, FMM (flexible manufacturing modules), and FMS's. Primrose defines FMS's as a development of FMM's, and FMM's as a development of CNC machines. Primrose identifies the advantages afforded by the development of CNC machines into FMM's, and from FMM's into FMS's, but does not identify flexibility specifically as an advantage. Instead he identifies the reduction in set-ups as a key advantage of FMM's over individual CNC machines.

Primrose further identified decreased lead times as an advantage of FMS over FMM's. Achieving shorter lead times, as Primrose stated, is highly dependent on the interchangeability of the roles of individual machines in the FMS. Interchangeability of machines could be expressed as a function of the range flexibility of individual machines.

Nagarajah and Thompson (1994) measured flow time and number of parts produced in a cell. These measures, they equated with operational flexibility. Initially they identified a need to reach an optimal cell size to maximise product range and minimise throughput times. To further investigate this, Nagarajah and Thompson simulated two manufacturing systems: a large cell that can process five part types; and five small cells which can each process one part type.

Cart speed, machine reliability and machine flexibility were varied and the performance in terms of flow time and output of products were measured. It should be noted that increased machine flexibility meant a machine being able to perform two processes rather than one. The paper concludes that increasing transporter speed and machine flexibility improves the performance of large manufacturing cells in relation to small manufacturing cells.

A similar method of indirect measurement is taken by Byrne and Chutima (1995) who measure mean flow time and mean tardiness from a series of simulations of FMS's. These measures are used to indicate improved routing flexibility. It is concluded that routing policies, the number of alternative machines and penalty for using alternative machines have significant impact on the performance of the systems. An interesting finding was the reduction in performance where significant penalties were incurred for using alternative machines. Intuitively one would expect alternative machines to increase performance.

From the research outlined it can be seen that indirect measures of flexibility can be useful in exploring the influence of flexibility. The controlled experiments conducted have enabled researchers to see how specific types of flexibility can improve performance. Most of the research outlined above has been conducted on simulators, where all of the factors influencing the manufacturing system can be controlled. In actual manufacturing systems it is not possible to control such factors without unreasonably limiting production activities. It is inevitable that factors such as machine loading or product mix will influence performance measures, for example through-put time or mean tardiness. This indicates that indirect measures can only be used to measure flexibility in highly controlled environments such as simulators. Hence there are, limitations to indirect measures' usefulness.

4.3 Financial Evaluation and Justification of Flexibility

One of the major reasons for determining a value for flexibility is to allow the proposal and approval of capital projects that improve flexibility (Blackburn and Millen, 1986). Many companies take different approaches to project proposals, depending on their financial, legal and cultural structure. The justification of projects that improve so called unquantifiable criteria such as flexibility or quality has long been an area of interest to managers, engineers and accountants. It is important that such criteria are taken into account when approving projects, in order that a company can take advantage of opportunities; conversely it is also important that companies do not undertake projects simply as an act of faith, thereby risking capital on projects that may not benefit the company.

Slagmulder and Bruggeman (1992) review a number of case studies concerning investment in flexible technologies. From these case studies they derive a number of conclusions:

1. The explicit definition of the manufacturing strategy justification contributes to the effectiveness of the financial justification.
2. The use of traditional financial justification tools such as IRR (internal rate of return) have become of secondary importance to other factors.
3. The existence of a project champion is not a sufficient factor for success.

However, despite these valid conclusions they do not propose an alternative methodology for financial justification of flexibility but simply acknowledge that " *no consensus exists about which of the different decision-making aspects are most likely to affect success or failure* ".

Naik and Chakravarty (1992) acknowledge the problems associated with justifying projects concerned with new technology. They identify the need to quantify long term strategic benefits such as quality, flexibility and delivery dependability. Their comprehensive review of techniques that are available for project justification identifies a number of different approaches including: Economic, such as payback and internal rate of return; Analytic such as portfolio analysis and risk analysis; and Strategic and Integrated approaches.

Naik and Chakravarty (1992) reviewed the available economic, analytic and strategic and integrated approaches, and identified them as only addressing a limited aspect of a complex problem. They suggest that the integrated approaches provide the best method but the strategic and the financial aspects should be "decoupled". To achieve this a three phase framework is suggested of strategic, operational and financial evaluation.

Naik and Chakravarty acknowledge the existence of methods for financial and operational evaluation, but identify the need for a strategic evaluation method. A method is also outlined for evaluating technology in terms of strategic importance.

This is achieved by initially relating competitive strategy such as innovation to a number of market requirements such as wide product ranges. The market requirements are then related to a number of manufacturing system attributes, such as ability to cope with a large number of product designs. These relationships are expressed in terms of an importance rating, i.e. very high, high, medium, low and not relevant. From these relationships it is possible to establish how important a system attribute is to a competitive strategy. Once this is achieved it is then possible to identify manufacturing systems that have the required system attributes to meet the competitive strategic needs of the company. This method to some degree encompasses the measurement of flexibility in that it can be used to assess the benefits of flexibility e.g. the ability to cope with a large number of product designs. However, it does not deal with the subject of assessing direct measures of flexibility.

It can be seen from the research outlined above that applying conventional methods to justify flexible technologies has severe limitations. Both Naik and Chakravarty (1992) and Slagmulder and Bruggeman (1992) identify the need to include strategic as well as financial justification in this process. Slagmulder and Bruggeman (1992) suggest a complex and subtle combination of these two approaches. They have also used a rating scheme that classifies the importance of manufacturing system attributes.

4.4 Modelling Flexibility

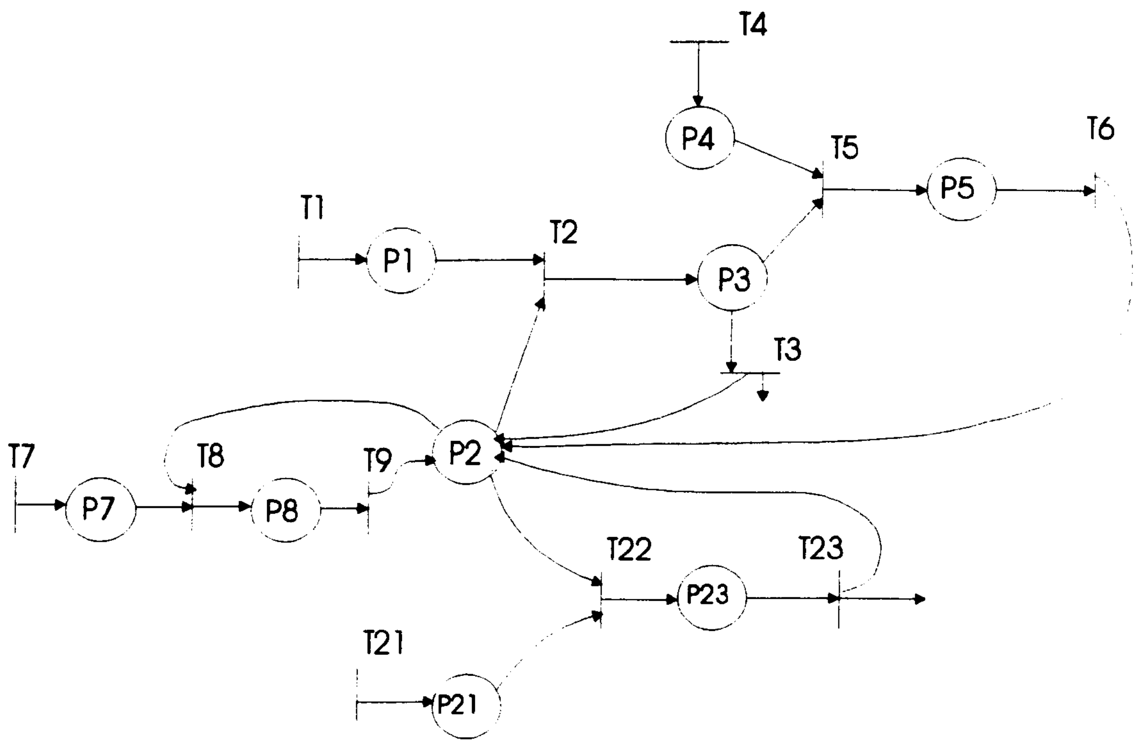
Researchers, having noted the problems associated with numerical assessment of flexibility, have applied modelling techniques to overcome the problem with two main techniques being applied, Petri nets (Barad and Sipper 1988 and Ito 1987) and conceptual modelling (Dooner 1991).

4.4.1 Petri Nets

Petri Nets are a system of modelling that can be used for "discrete-event-dynamic systems" (Decistere, Harhalakis, Proth, Silva and Vernadat, 1993). Petri Nets can show discrete processes and events and indicate time scales. They were originally developed for information systems applications, but have been used in a range of applications associated with logic and engineering.

Barad and Sipper (1988), in their first paper outlined a method for using Petri Nets to model manufacturing systems and from this model they measured operational flexibility. Operational flexibility is defined by Barad and Sipper as the ability to change the order in which operations are performed on a product. It is proposed that Petri Nets are used as a simple simulation tool. The ability to cope with disturbances such as breakdowns is measured, for systems with varying levels of operational flexibility.

Barad and Sipper (1990) developed their initial ideas to incorporate flexibility defined as dependent on operations' variety and machines' set-ups. A Petri Net is developed for a machine that can process two products. Figure 4.1 shows the Petri Net for the machine; Table 4-1 shows the incidence matrix for this Petri net.



T_1 = part arrival

T_2 = start part processing

T_3 = end part processing

T_4 = failure arrival

T_5 = start tool change

T_6 = end tool change

T_7 = change-over arrival

T_8 = start of set-up

T_9 = end of set-up

T_{21} = arrival of part 2

T_{22} = start processing part 2

T_{23} = end processing part

Figure 4.1: Petri Net of a Machine Barad and Sipper (1990)

In Figure 4.1, transitions are shown as bars and are identified $T_1, T_2 .... T_n$. and places are shown by circles and identified $P_1, P_2 .... P_m$. Places and transitions are then connected by arcs that indicate a relationship between a particular place and transition. The incidence matrix expresses the network of arcs mathematically with '1' representing an arc from a transition to a place and '-1' representing an arc from a place to a transition.

Table 4-1: Incidence matrix of Petri Net in Figure 4.1

P \ T	1	2	3	4	5	6	7	8	9	21	22	23
1	1	-1										
2		-1	1			1		-1	1		-1	1
3		1	-1		-1							
4				1	-1							
5					1	-1						
7							1	-1				
8								1	-1			
21										1	-1	
23											1	-1

Barad and Sipper (1990) have developed an expression shown in Equation 4-12 for the Flow Recovery ratio *(FR)* of the machine. *FR* is defined *as "the ratio of the maximum total flow of the machine when machining two parts to the maximum total flow when machining only one part* " i.e. it is an expression of loss of throughput due to the necessity to machine two different products instead of one. This relates to flexibility, in that a machine that has a *FR* of 1 is able to manufacture two products just as easily as one and therefore has high flexibility. A machine which has an *FR* of less than one has lower flexibility. Barad and Sipper state *"flexibility may be quantified as the flow recovery"*, FR is numerically expressed as:

$$FR = E\left[FD - r_s/(1-r_f)\right] + 1 - FD \qquad for \quad r_s/(1-r_f) < FD \qquad \text{Equation 4-12}$$

$$else \quad FR = 1 - FD$$

Where:

$E = Z_3/Z_{23}$

$FD = (I_{1.max} - I_1) / I_{1.max}$

$r_s = I_7 \times Z_8$

$r_f = I_4 \times Z_5$

$I_{1.max} = (1 - I_4 \times Z_5 - I_7 \times Z_8) / Z_3$

Z_3 = processing time product 1

Z_4 = waiting time of a failure

Z_5 = repair duration

Z_8 = set-up time

Z_{23} = processing time of product 2

I_j = flow through transition j where j = (1,2 ....n)

Using the above equation Barad and Sipper have identified the relationship between *FR* against machine utilisation and have concluded that a system's ability to cope with change is highly dependent on set-up times and the machine's versatility.

It should be noted that Barad and Sipper (1988) acknowledge the high level of complexity of Petri net models for larger systems and suggest modular modelling as a solution. Modelling a series of modules would, however, considerably increase the time required to construct models.

4.4.2 Conceptual Models

A conceptual model is a representation of a system that requires interpretation to yield any results. Dooner (1991) developed a conceptual model, the first stage of which is illustrated in Figure 4.2, it shows a systems application domain and a representation of expanding this domain. The system application domain represents the scope of ability of the manufacturing system.

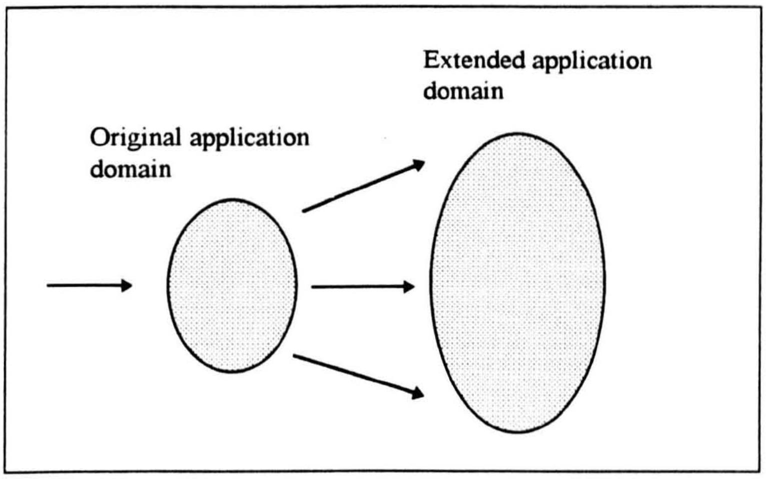


Figure 4.2 Expanding an Application Domain (Dooner 1991)

Dooner also states that at any one time a system or machine can only be in one state. This implies that the application domain consists of a number of discrete states that Dooner calls state domains. Dooner also outlines the structure of his conceptual model, which consists of many interconnecting "concept nodes". Where, concept nodes represent parts of the manufacturing system, this is shown in Figure 4.3 in which concept nodes are used to model a universal profiling machine.

Dooner proposed three concepts that need to be modelled to outline the flexibility of a system in terms of its application domain where an application domain represents what a system can do.

1. The range of the domain.
2. The time-effort to move around the domain.
3. The time-effort to expand the range of the domain .

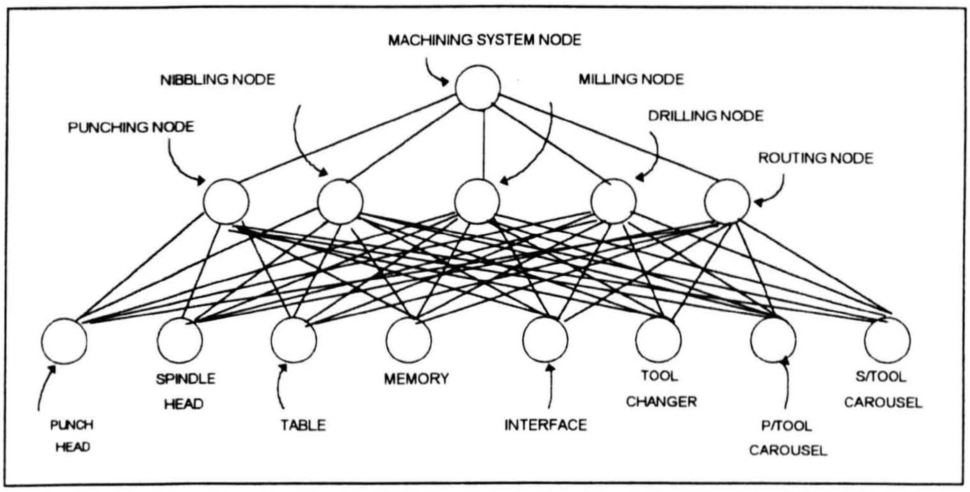


Figure 4.3 A Nodal Model of a Universal Profiling Machine (Dooner 1991)

Associated with each node are three items of data, the concept name (e.g. part program store), the flexibility descriptor(e.g. program switching time) and a value for flexibility descriptor (e.g. five seconds switching time). It can be seen from Figure 4.3 that the nodal model is complex for a single piece of machinery. For an entire system this would be extremely complex.

4.5 Summary

Sections 4.1 to 4.4 have examined a range of approaches to measuring flexibility. The diversity and complexity of these approaches illustrate the difficulty in measuring flexibility. The use of modelling techniques has the advantage of providing a richer picture than a simple numerical measure, and thus better reflects flexibility's and manufacturing's complex nature (Vernadat, 1996). The disadvantage of this approach is that it is less easy to compare models for the purposes of decision making.

The relationship between the types of flexibility measure explored in Sections 4.1 to 4.3 is summarised in Figure 4.4. This shows that numerical measures of flexibility are direct measures of flexibility. These measures attempt to measure flexibility itself. Indirect measures of flexibility, which measure manufacturing systems performance flexibility have two influences:

1. Types of flexibility.
2. Other Manufacturing system variables.

Financial measures of flexibility interpret the benefits of flexibility into a monetary value and also have two direct influences:

1. The manufacturing system performance.
2. The commercial position of the company.

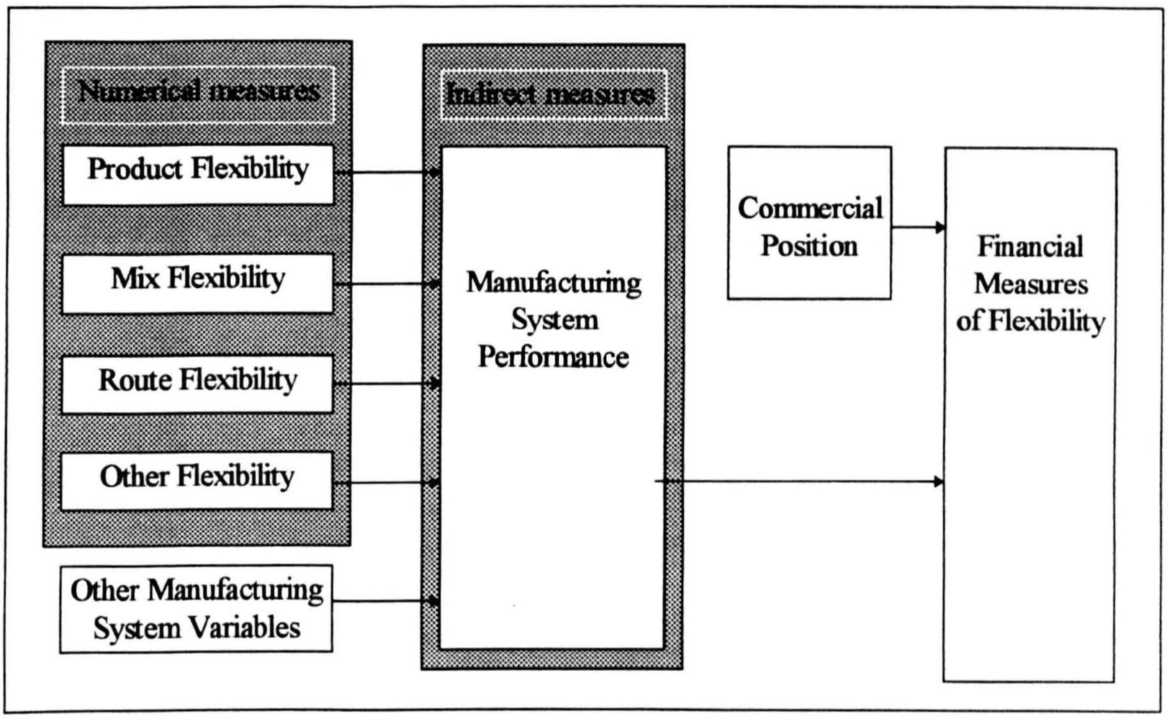


Figure 4.4: Relationship between Measures of Flexibility

Thus it can be concluded, that numerical measures of flexibility provide the most direct measure of flexibility and are least influenced by distorting factors such as manufacturing system variables other than flexibility and by the commercial position of the company.

5. DEVELOPMENT OF A CONCEPTUAL MODEL

5.1 Introduction

This chapter describes the development of a conceptual model that is used to represent the flexibility of a manufacturing system. This model is then used to provide a basis for the two numerical measurement methods that are developed in Chapters 6 and 7. The conceptual model provides a context for the results of the numerical methods, by relating the output from these two methods to the manufacturing system being examined. The model, used in this way derives the benefits associated with modelling techniques, identified in Chapter 4, in that it provides not only a rich picture of the system flexibility but, also by using numerical indicators, it avoids the disadvantages associated with using qualitative models, i.e. it is able to directly compare alternative systems.

5.2 Model Development

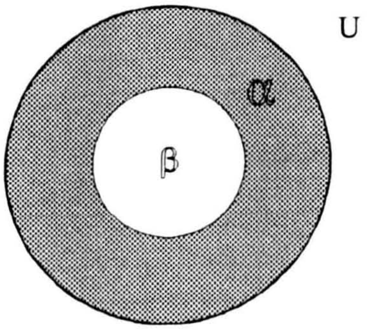
The conceptual model developed for this research was derived from the model proposed by Dooner (1991) (Figure 4.2). in which an application domain is described, which is an abstract concept to represent the ability of a manufacturing system. Here, the larger the application domain, the greater the ability of the system, and hence the greater its flexibility. In the model shown in Figure 4.2., Dooner represents the concept of an application domain as a shaded area. For the model derived in this research, Dooner's concept of an application domain has been applied specifically to the manufacture of products. This approach was chosen because producing products is the primary function of manufacturing systems and it is through products that customers principally perceives the manufacturer. Thus area β shown in Figure 5.1 represents the application domain of the manufacturing system in terms of products it can make.

Figure 4.2 also shows the transition of a manufacturing system from an original application domain to an extended application domain. This illustrates a different type of flexibility which relates to changes in the ability of a manufacturing system. In the current research this is shown as area α in Figure 5.1 which represents an extended application domain of the products the manufacturing system could be modified to manufacture.

In addition to the model shown in Figure 4.2, Dooner outlines the concept of machine or system states. He asserts that a machine or system can have many states, but can only be in one state at one time. Relating this to the conceptual model for this research, area β in Figure 5.1, represents a set of states that the manufacturing system must adopt to produce a current product. Each discrete state represents one product. Summarising and expressing this more simply:

1. Area β represents the system states for products that the company *currently* makes. This area is finite and is composed of discrete states, with each state representing a specific product.

2. Area α represent the system states for products the company *could* make. This area has a finite boundary, but consists potentially of an infinite number of different products.
3. The area U lies outside area α and is the universe of all potential products. It is infinite and unbounded.



Key:

α - Set of manufacturing system states for potential products

β - Set of manufacturing system states for actual products

U - Universe of all products

Figure 5.1 Simple Model of Product and Mix Flexibility

Examining this model in terms of Slack's (1990) definitions of flexibility, range and response, range can be identified in Figure 5.1 as the size of areas α and β. Response can be defined into three types, identified in Table 5-1.

Table 5-1: Response Types for the Simple Model

Response types	Description
Response 1	The time it takes to change between states in area β i.e. the amount of time it takes to change from manufacturing one product to another.
Response 2	The effort it takes to enlarge area β i.e. the time and cost of introducing a new product to manufacturing.
Response 3	The effort it takes to enlarge area α. i.e. increasing the manufacturing capabilities of the system.

5.3 Development of the Simple Model of Product and Mix Flexibility

If the boundaries of areas α and β and the universe of states "U" are considered, it is possible to identify the system states in area β (i.e. those states which are required to make the current product range), and thus it is possible to define the boundaries of area β. However, defining the boundaries of area α is less straightforward .

Area α is defined as the set of states required to make a potential product. Defining these potential products presents a difficulty, because given sufficient effort, the manufacturing system may be changed so radically as to be able to manufacture any product, thus, it can be considered that the boundary between area α and "U" is blurred.

In order to resolve this problem, the model shown in Figure 5.1 has been modified as shown in Figure 5.2 such that the boundary between U and area α is ambiguous. System states which require little modification to the manufacturing system, are differentiated from states which require large modifications to the manufacturing system, by their distance from the edge of area β. For example, the state which relates to a new product that merely requires the programming of a CNC machine,

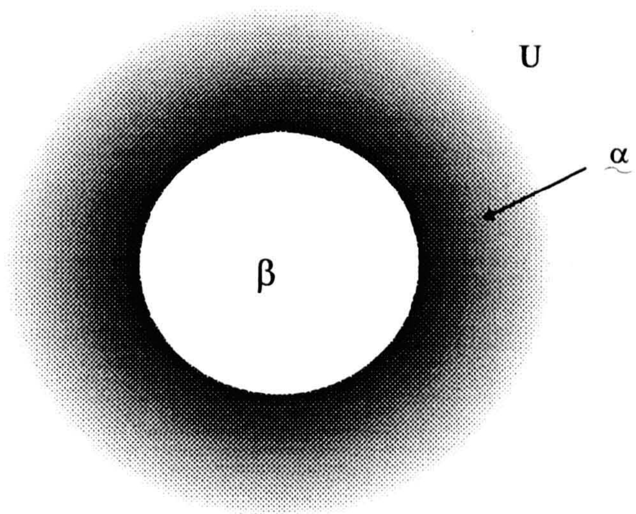


Figure 5.2 Model with Fuzzy Area $\underset{\sim}{\alpha}$

is placed near to the edge of area β i.e. in the darker area. The state for products that require small increases in investment levels such as a jig are placed further away from the edge of area β. The states for products that require higher levels of investment such as expensive production machinery, are placed still further away from area β i.e. almost into the U area.

The modifications shown in Figure 5.2 results in set α possessing a fuzzy boundary as opposed to a classical or crisp set boundary. The number of states in set β, known as the cardinality, is equal to the number of products. The cardinality of set α is infinite, because there are an infinite number of products possible within area α. This coheres with theory for all fuzzy sets which states that cardinality is one of the significant differences between classical sets and fuzzy sets (Ross 1995).

The existence of fuzzy boundaries results in the model shown in Figure 5.2 being difficult to convert into a working model, since these fuzzy boundaries are difficult to express simply in terms of set membership. In order to overcome this problem area α has been modified to a series of step changes as shown in Figure 5.3.

These step changes are shown as a number of concentric bands for area α, with each band representing varying levels of financial investment i.e.:

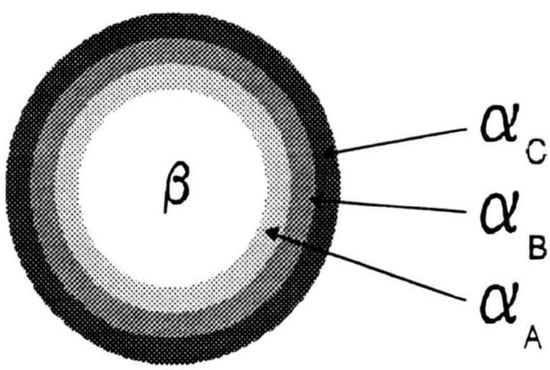


Figure 5.3: Model Showing Step Changes in Area α

α_A represents the range of products that can be manufactured simply through changes in the information system, such as process plans or computer programs.

α_B represents the range of products that can be manufactured through minor hardware changes such as jigs and fixtures.

α_C represents the range of products that would need a major cost investment in the manufacturing system in order to produce them.

The definitions of the costs of minor and major changes vary between industries. For example a minor change may be defined as costing up to £500 and a major change between £501 and £6,000.

5.4 Development of the Detailed Model

In order to use the conceptual model shown in Figure 5.3 to assess the flexibility of a manufacturing system, the user would need to know the size of each area and cost of responses 1 to 3 identified in Table 5-1 . Relating these responses and areas to Slack's (1990) typology, mix range flexibility is equivalent to the size of area β and mix response flexibility relates to response 1 in Table 5-1. Although the area occupied by the α sets relate to Slack's product flexibility, there is no direct equivalence for the α sets, as Slack has not considered product flexibility in such a way. Product range flexibility relates to the size of the α sets, as mix range flexibility relates to the β set. Product response flexibility has been simplified from Slack's (1990) original concept i.e. from a continuous to a discrete measure as defined by the individual α sets. The response between the α sets is inherent in their definition, i.e. the response from α_A to α_B is identified by the response cost at which area α_B is specified.

5.5 Measuring Product Flexibility

To measure the α sets in Figure 5.3 it is necessary to consider the potential of a manufacturing system in terms of what could be manufactured by the system. To achieve this there is a need to map the ability of the manufacturing system in terms of the characteristics of the products each part of the manufacturing system can produce. A method of achieving this is outlined in Chapter 7.

5.5.1 Measuring Mix Flexibility

To measure mix flexibility there is a need to measure both range and response. Mix range flexibility, can be measured by identifying the *number* of products the company produces (Muramastu, Ishii and Takahashi, 1985) and is represented by the size of the pool of products from which products can be selected i.e. the cardinality of β. This provides an adequate measure of mix range flexibility.

Mix response flexibility is represented by the ability to change the product being manufactured (from the pool of products) e.g. the time it takes to change from manufacturing one current product to another. The method outlined below to measure mix response flexibility builds on the work of Chryssolouris and Lee (1992) who state that the flexibility for a machine is inversely proportional to the sensitivity to change (STC) as shown in Equation 5.1. Where:

$$STC = \sum_{i=1}^{n} Pn(X_i)\Pr(X_i)$$ **Equation 5-1**

Where:

n= the number of potential changes,

i= the change index,

X_i= the *i*th potential change,

$Pn(X_i)$= the penalty of the *i*th potential change and

$Pr(X_i)$= the probability of the *i*th potential change.

Chryssolouris and Lee use this measure for long term changes in manufacturing systems, and have examined the ability of alternative manufacture systems to produce new products. This approach can, however, also be used for short term changes which occur when changing from manufacturing one product to another. STC can be evaluated in terms of mix response flexibility by regarding the change identified in Equation 5.1 as a change from one product to another. The penalty incurred is the set-up time and the probability of the change occurring is the probability of a set-up being required. Substituting in to Equation 5.1:

$$STC = \sum_{s=1}^{s=t} P_s . dur_s$$ **Equation 5-2**

Where:

P_S = the probability of a set-up s occurring

dur_S = the duration of set-up s

t = the number of different set-ups

Thus STC is expressed in time^{-1}, and flexibility in units of time. In order to calculate the STC and hence mix response flexibility, there is a need to evaluate each of the components P_S, dur_S and t. The number of different set-ups, t, can be found from production data. The duration of a set-up, dur_S, can be timed in the case of an existing system or estimated in the case of a proposed system. The probability of a set-up occurring P_i has to be taken from historical data or calculated from the probability of a *product* occurring. However, it should be noted that a product occurring does not always mean a set-up is required.

In order to quantify P_S i.e. the probability of set-up "s" occurring , an assumption as to when a set-up occurs needs to be made. For the purposes of this model it is assumed that when a product follows an identical product, no set-up occurs. Shown below in Figure 5.4 is an example of the occurrence of set-ups for four products, j, k, l and m.

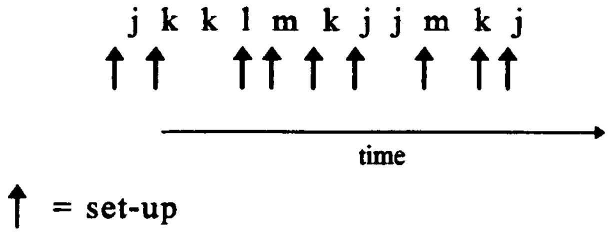


Figure 5.4 Occurrence of Set-ups

It can be seen that if these products are re-ordered then a varying number of set-ups may occur. Thus for any set of products the order of products will affect the total time spent in set-up. To minimise set-up for a group of products, all the same type of product should be grouped together. Thus for the group of products shown in Figure 5.4 the total number of set-ups can be reduced to four, one for each type of product, thus the order will be jjjkkkklmm. A scheduler would naturally try to group the same products together, reducing the overall time spent in set-up. However, market forces often force the sequence of products into a less optimal order.

Thus for a group of products the total time spent in set-up is not fixed, and it is dependent on the order of the products. Therefore, for a group of products, a set-up time per product may either be calculated for a specific sequence of products, or a mean and standard deviation may be calculated for all the different possible sequences of the products. By generating the set-up time all possible sequences it can be shown that the distribution generated approximates to a normal distribution. Adopting the distribution approach a method for measuring the mean STC and the standard deviation associated with it is developed in Chapter 7.

6. MEASURING PRODUCT FLEXIBILITY

For practical use, the conceptual model outlined in Chapter 5 needs to be interpreted in a quantitative manner. This chapter outlines the first stage of this interpretation by identifying a method for measuring product flexibility, represented in the conceptual model by the α areas.

6.1 Requirements for a Product Flexibility Measure

In order to comply with objective 5 stated in Section 1.5, (i.e. that a measure of flexibility should be able to assess flexibility in different types of industry), it is important that the product flexibility measure should be able to cope with different types of manufacturing system. Hence, the measure should be able to :

1. Compare systems with different numbers of machines.
2. Cope with parallel and alternative processes.
3. Reflect lack of flexibility for sub-systems that have no ability to manufacture a particular type of product.
4. Reflect the relative importance a manufacturer may place on having the potential to develop particular types of product.

6.2 Theory of Calculating Product Flexibility

A measure of the product flexibility of a manufacturing system, needs to assess the ability of the system to make different types of products. In order to achieve this, the manufacturing system is divided into simpler sub-systems, such as individual machine tools. Each sub-system is then considered in terms of its ability to manufacture different types of product.

In this respect, when assessing the ability of a sub-system to make potential products it is necessary to identify criteria by which the individual sub-systems will be measured. This aids consistency of measurement between sub-systems and providing the correct criteria is chosen, ensures that value is placed only on the potential to manufacture products which contribute to manufacturers' competitiveness.

The criteria for assessment of the sub-systems is based on a number of product characteristics such as size, or material type. These characteristics normally relate to the physical attributes of the product and often identify the processing requirements. These characteristics are then expressed as specific criteria, such as numerical ranges and it is against these criteria, defined within a product characteristic that sub-systems are assessed.

Identifying product characteristics can be achieved using a suitable group technology classification scheme such as VUOSO or VUSTE (Gallagher and Knight, 1973). Using these schemes an example of a characteristic would be size of maximum product diameter, with the specific criteria being 0 to 50mm, 50mm to 100mm and greater than 100mm. A characteristic's criteria may also be defined qualitatively, for example for the characteristic shape the criteria could be rotational, flat, extruded or prismatic.

From Figure 5.3 it can be seen that the evaluation of sub-systems against the specified criteria needs to be performed in terms of the graduations of the α rings. This is performed by denoting an A, B or C for each sub-system against a particular criteria. Where:

1. An "A" represents a sub-system that can achieve the criteria with no changes to the manufacturing system.
2. A "B" represents a sub-system that can achieve the criteria with small to medium cost changes
3. A "C" represents a sub-system that can achieve the criteria with medium to high cost changes.

Table 6-1 illustrates for a small FMS an example of assessing the characteristic "component diameter". The diameter of the product the manufacturing system currently makes is 30mm, hence all the sub-systems are categorised as "A"s for the 0-40mm criteria. However, it can be seen from Table 6-1 that as the diameter increases it becomes more expensive to enable each of the sub-systems to deal with these larger diameters. It can also be seen that the robots have a particular problem in this respect. In practice this arises because the robots have the same type of gripper that can only handle up to 40mm component diameters.

Table 6-1 Example of Categorisation for a Characteristic

Characteristic: component diameter	Dimensions (in mm)			
Sub-system	0-40	40-80	80-200	200-400
CNC lathe	A	A	C	C
CNC miller	A	A	C	C
Gauge	A	A	A	C
Visual inspection	A	A	A	C
AGV	A	A	A	A
Robot R1	A	B	C	C
Robot R2	A	B	B	C
Robot R3	A	B	C	C
Robot R4	A	B	B	C
Carrousels	A	B	B	B
Software	A	A	A	A
Output station	A	B	B	B
Input station	A	B	B	B

To fully assess the product flexibility of a manufacturing system it is necessary to categorise the sub-systems in terms of several characteristics. The table for each individual characteristic is termed a "characteristic layer". These layers build up into a three dimensional matrix as shown in Figure 6.1

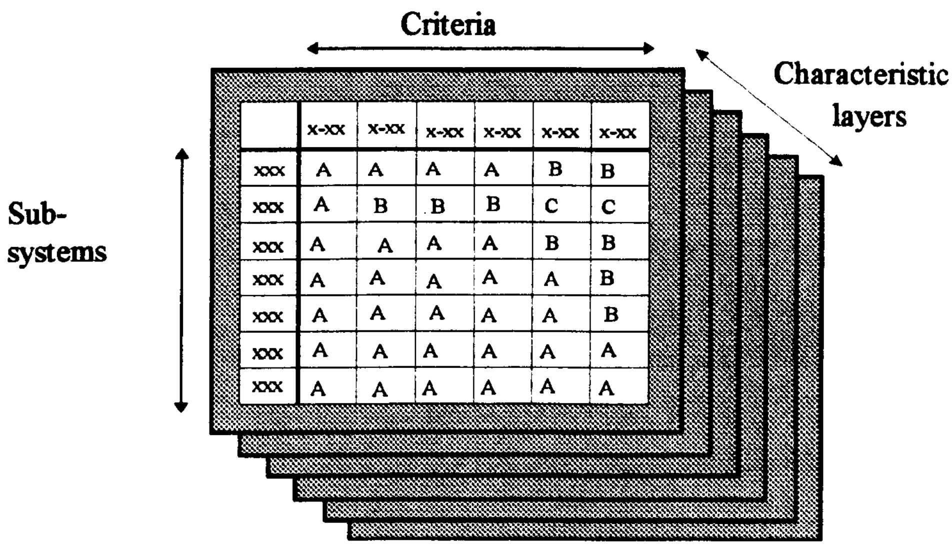


Figure 6.1: Three Dimensional Matrix of Product Flexibility

6.3 Calculating the Total Response Cost

From the three dimensional matrix shown in Figure 6.1 a single comparative measure can be developed. This measure can be developed by assuming that the manufacturer would eventually want to manufacture all possible products. It is then possible to calculate the cost of incorporating all the characteristic criteria in the manufacturing system. A cost is allocated to each of the classifications A, B and C and the total summed for the system. The costs allocated to each of the categories is determined by the user, and should reflect the average cost of implementing each of the category of changes. This measure is termed "the total response cost" or TRC.

Table 6-2 shows the calculations for three FMS's in which the cost allocated to A's is zero, to B's is £500 and to C's is £3000. The product of the number of each A, B, or C and its cost allocation is summed to give a total cost.

Table 6-2: Calculations of Product Flexibility for Three Alternative Systems

	FMS 1		FMS 2		FMS 3	
No of A's	109	109 X 0 = 0	100	100X 0=0	113	113X 0=0
No of B's	19	19X 500 = 9500	23	23X 500 = 11500	8	8X 500=4000
No of C's	35	35X 3000 = 105000	40	40X 3000 = 120000	42	42X3000=126000
Total (TRC)		114500		131500		130000

It can be seen from Table 6-1 that FMS 1 has the lowest total cost and is therefore the most flexible system with FMS 2 having the highest total cost and therefore is the least flexible system in terms of product flexibility. It should be noted that the totals calculated in Table 6-2 are an inverse measure of flexibility as the system with the highest TRC has the least flexibility.

6.4 Development of Total Response Cost

Outlined in Section 6.3 is a basic method for assessing product flexibility and the total response cost. This section examines this measure with respect to the requirements identified in Section 6.1 and develops the measure where necessary to meet these requirements.

6.4.1 Comparing Systems with Different Numbers of Sub-systems

Normally designers of manufacturing systems, need to compare alternative systems, which have differing numbers of machines, or sub-systems. It is therefore necessary to investigate whether systems that have different numbers of machines or subsystems can be compared using the TRC measure.

The TRC is dependent on the number of machines in the system, each additional machine can contribute a cost to the TRC. This however, does not present a problem, because, it is important that the TRC reflects the relative costs that may be incurred through either a system having fewer complex machines that require high cost changes, or a system having many simple machines that all require simple modifications to allow a product introduction.

6.4.2 Parallel Processes

It is likely that some manufacturing systems will contain processes that operate in parallel. Here some individual characteristic criteria may not be appropriate for all parallel processes. For example if two sub-systems operate in parallel, with one processing liquids and the other solids, it would not be sensible to expect the sub-systems that processes liquids to be able to deal with different hardness materials, equally it would not be sensible to expect the sub-systems that processes solids to be able to pump. Thus it is necessary to identify these inappropriate criteria, in the matrix as n/a which has a cost weighting of zero.

6.4.3 Sub-systems that Cannot Achieve a Criterion of a Characteristic

It can be anticipated that despite a characteristic being appropriate, a machine or sub-system may not have the capability to achieve a criteria without replacing the machine or sub-system entirely. This has two implications, firstly there should be an upper limit to the cost range of a C change to a machine. If there is not, then any change could be incorporated into the system, by replacing the machine or sub-system with another which is capable, in which case any criteria could be achieved and the outer α_c boundary shown in Figure 5.3 becomes fuzzy to incorporate the universe of all possible products. The second effect is that machines that breach the upper limit for C costs, should have a detrimental effect on the measurement of product flexibility i.e. by increasing the total response cost. Hence an additional, high cost weighting should be allocated if a sub-system cannot achieve a criteria. For example, the cost weighting for A, B and Cs may be £0, £500 and £3000 and if the user wishes to discriminate heavily against sub-systems that cannot achieve a particular criterion, the weighting applied could for example, be in the region of £200,000. If the user wishes to consider more favourably systems which cannot achieve a criterion, then the weighting may be much less e.g. £6000. When a sub-system cannot achieve a criteria it is indicated in the matrix as n/p.

6.4.4 Weighting of Characteristics

To reflect the relative importance placed on possessing the potential to develop particular types of product, a manufacturer will regard some criteria as more important than others. For instance, if a company regarded the ability to make components with larger diameters as likely to have more potential value than other characteristics, the company would want to be able to identify systems that have the ability to make this type of product.

This requirement can be provided by introducing a weighting factor V. Such that all A, B and C's from the characteristic "component diameter" use a cost factor that has been multiplied by V. If V>1 this will tend to increase the relative cost of the characteristic, and so favour systems which have less costs associated with developing products with this characteristic.

6.5 Calculating TRC

Consider three systems X, Y and Z, which have differing numbers of machines and hence different numbers of cells. Let the A, B, C and n/p categories be costed at £0, £1,000, £4,000 and £10,000. Table 6.6 shows the number of A, B, C, n/a and n/p cells for each system. One characteristic, colour, is deemed to be of more importance that the other characteristics, and so has an additional weighting of 1.2.

Table 6-3: Summary of Data for Systems X, Y and Z

	System X	System Y	System Z
Total number of cells	150	170	200
No. of A's	81	86	90
No. of B's	22	10	20
No. of C's	35	35	40
No. of n/p cells	12	35	40
No of n/a cells	0	4	10
No. A's in Colour characteristic	14	16	15
No. B's in Colour characteristic	5	10	5
No. C's in Colour characteristic	3	5	5
No. of n/p cells in Colour characteristic	2	5	5
No. of n/a cells in Colour characteristic	0	1	0
TRC (in £)	289400	516000	595000

Using the data shown in Table 6-3 the TRC for each system has been calculated using the procedures shown in Appendix 1. It can be seen from Table 6-3 that system X has the lowest TRC (£289,400) and therefore the highest product flexibility, system Z has the highest TRC (£595,000) and therefore the lowest product flexibility.

6.6 Verification and Validation

A useful method of face validation for this application is to substitute relatively simple values into the model (Robinson 1994). These values allow the user to predict what the output of the model should be. It is often useful to use extremes of possible values as inputs, as the result from using this data can often be predicted. In this case two situations can be modelled:

1. The system that has the ability to make all possible changes. It can be predicted that this system has a very high level of flexibility. For example if there are 200 cells all would be A's and there would be no n/a or n/p cells. This would give a TRC of zero which indicates a high level of flexibility.
2. The converse system, in which no changes are possible. This system will have a very low level of flexibility. There would be the minimum number of A's, e.g. 60, which is the capability that is required to make the current product range. The remaining 140 cells would be rated as n/p. Using the same weighting used for systems X, Y and Z the TRC is £1,400,000 which indicates a low flexibility.

6.7 Summary of Measuring Product Flexibility

Product flexibility may be initially assessed by developing a three dimensional matrix as shown in Figure 6.1. A single measure can then be derived from this matrix which allows comparison of product flexibility between systems. This measure is termed the total response cost (TRC) and is an inverse measure of flexibility i.e. a low TRC indicates high flexibility. Individual TRC measures need to be developed using a manufacturers own product characteristics, criteria and cost categories.

7. MEASURING MIX FLEXIBILITY

This chapter outlines a method for measuring mix flexibility which is defined as the ability to change between the products that a company currently makes. This is represented by the β area in Figure 5.3. The measurement method developed in this chapter is tested on three hypothetical manufacturing systems A, B and C. The results obtained are validated against data from a simulation.

7.1 Manufacturing Systems A, B, and C

The three systems used to test the method developed are as follows:

1. System A is a single machine system. The simplicity of this system is used to highlight basic flaws in the method.
2. System B is a simple multiple machine manufacturing system where products occur with equal probabilities. This system is used to ensure the method is valid for systems with several machines.
3. System C is a more complex multiple machine system with products that occur with unequal probabilities. This ensures that the method can cope with the complexity inherent in real manufacturing systems

7.1.1 System A

System A consists of a single machine on which four parts j, k, l, and m are processed. The parts have an equal probability of being the next part to be processed. The durations of the set-up for each part vary and are shown in Table 7-1.

Table 7-1: System A Data

Product	Duration of set-up in minutes	Probability of occurrence
j	7	0.25
k	5	0.25
l	10	0.25
m	6	0.25

7.1.2 System B

System B consists of five machines and four products j, k, l, and m. It is designed to represent a simple manufacturing cell. All products are processed within the cell, however, not all the machines are used for each product. The process routes for each part are shown in Figure 7.1, with part j for example being processed on machines 1 and 3.

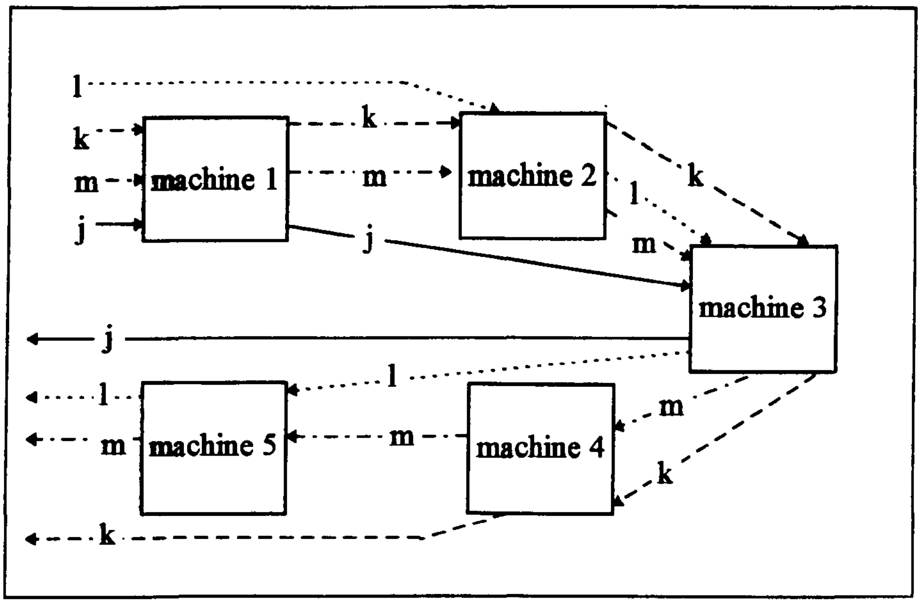


Figure 7.1: Process Routes for System B

The products have an equal probability of being the next part to enter the cell, and the set-up durations are shown in Table 7-2.

Table 7-2: System B Data

		Set-up duration in minutes				
Product	Probability of occurrence	Machine 1	Machine 2	Machine 3	Machine 4	Machine 5
j	0.25	5	10	7	6	-
k	0.25	4	-	5	6	-
l	0.25	-	8	10	-	3
m	0.25	7	8	6	5	6

7.1.3 System C

This system has the same process routes as system B, however, the probabilities of a product entering the cell are not equal as for system B, but vary as shown in Table 7-3.

Table 7-3 System C Data

Product	Probability of occurrence
j	0.2
k	0.4
l	0.1
m	0.3

7.2 Method for Measuring Mix Response Flexibility

Chapter 5 identified the work of Chryssolouris and Lee (1992) as a basis for measuring flexibility. They stated that the flexibility of a machine is inversely proportional to its sensitivity to change (STC). Chryssolouris and Lee applied their model to measure for long term flexibility. Section 5.3.2 identifies how this model can be modified to provide a short term measure for mix flexibility. Equation 5.2 is derived from this modification and is shown here as Equation 7.1 for ease of reference.

$$STC = \sum_{s=1}^{s=t} P_s . dur_s \qquad \text{Equation 7-1}$$

Where:

P_S = the probability of a set-up s occurring,

dur_S = the duration of set-up s, and

t = the number of different set-ups.

As identified in Section 5.2.3 in order to calculate STC and hence mix response flexibility, there is a need to evaluate each of the individual components P_S, dur_S and t. The number of different set-ups, t, can be found from production data. The duration of a set-up dur_S can be physically measured in the case of an existing system or estimated in the case of a proposed system. The probability of a set-up occurring P_i has to be taken from historical data or calculated from the probability of a product occurring.

Section 5.3.2 also identifies that for a group of products, the order in which the products are processed will affect the total set-up time. This means that there is a need to develop:

1. A mean STC per product for the distribution of all sequences of product based on the probability of a product occurring.
2. A standard deviation of the STC distribution.

The probability of a set-up occurring P_S, can be calculated from the probability of a product P_i occurring. When performing this calculation, account must be taken of the probability of the same product occurring consecutively, i.e. when no set-up is required, as shown in Figure 5.4. Thus the probability of a set-up occurring is equivalent to the probability of a product occurring P_i followed by a dissimilar product probability $(1-P_i)$. The probability of a set up occurring is therefore:

$$P_S = P_i(1-P_i) \qquad \text{Equation 7.2}$$

Hence Equation 7.1 becomes:

$$MSTC = \sum_{i=1}^{i=n} P_i(1-P_i)dur_i \qquad \text{Equation 7.3}$$

Where:

$MSTC$ = the mean sensitivity to change (for all sequences of product)

n = the number of different products.

It should also be noted that the duration of a set-up dur_s is the same as dur_i the set-up duration for product i.

The standard deviation may be calculated using the generic formula for the variance of a probability distribution (Freund and Simon, 1992) i.e.:

$$\sigma^2 = \sum (x-\mu)^2.f(x) \qquad \text{Equation 7.4}$$

Where :

σ= standard deviation,

μ = calculated mean,

x = the variable, and

$f(x)$ = the function from which the mean is calculated.

Substituting the probability of a set-up occurring, $P_i(1-P_i)$ for $f(x)$ with, $MSTC$ for μ and dur_S for x provides equation 7.5:

$$\sigma = \sqrt{\sum_{i=1}^{i=n} (dur_i - MSTC)^2 P_i(1-P_i)} \qquad \text{Equation 7.5}$$

Using Equations 7.4 and 7.5 the mean and the standard deviation for the sensitivity to change may be calculated for a single machine.

7.2.1 Multiple Machine Systems

In order to model systems B and C it is necessary to combine data from individual machines. In this respect, for a system in which all machines are in series and all products are processed on all machines, i.e. effectively a flow line, the $MSTC$ and SD are calculated as follows:

$$MSTC_Y = \sum_{j=1}^{j=m} MSTC_j \qquad \text{Equation 7.6}$$

$$SD_Y = \sqrt{\sum_{1}^{j=m} SD_j^2} \qquad \text{Equation 7.7}$$

Where:

m = the number of machines,

$MSTC_Y$ = the mean sensitivity to change for the system in series,

$MSTC_j$ = the mean sensitivity to change for a machine j,

SD_Y = the standard deviation for STC for the system in series, and

SD_j = the standard deviation for STC for a machine j

For systems where products have different processing requirements, the probability of using a particular machine, needs to be taken into account. Thus Equations 7.6 and 7.7 are modified to Equations 7.8 and 7.9 which now include the probability that a generic part will visit machine j.

$$MSTC_T = \sum_{j=1}^{j=m} P_j MSTC_j \qquad \text{Equation 7.8}$$

$$SD_T = \sqrt{\sum_{j=1}^{j=m} P_j SD_j^2} \qquad \text{Equation 7.9}$$

Where:

$MSTC_T$ = the mean sensitivity for the parallel system,

SD_T = the standard deviation for STC for the parallel system, and

P_j = the probability of a machine j being used for a part.

7.3 Validation Method

In order to validate the results from the method outlined in section 7.2 it is possible to compare them against similar measures (Robinson 1994). In order to develop suitable similar measures, $MSTC$ must be considered as the mean set-up time for a set of products Q for all orders of Q. i.e.:

$$MSTC = \sum_{1}^{v} \frac{x}{v}$$ Equation 7.10

Where:

set $\mathcal{A}$ ={x | x is mean set-up for an order of the products in Q },

$v = |\mathcal{A}|$, and

Q = a set of products.

The size of set $\mathcal{A}$, i.e. the value of v, becomes very large even for modest sizes of set Q. For example, for $|Q|$= 50 with 5 different products, and 10 of each type of product, $\mathcal{A}$ has 2.5×10^{61} members. This is derived from the formula for number of permutations in a set n, where there are k distinct objects and r_k is the number of each distinct objects i.e.:

$$number \quad of \quad permutations = \frac{n!}{r_1 \cdot r_2 \cdot \ldots \cdot r_k}$$ Equation 7.11

If a subset of $\mathcal{A}$ can be generated by another method, the mean of the subset members can be compared with the MSTC. This subset of data can be generated using a computer based manufacturing simulator, in this case using Promodel (1993). By inputting a product stream i.e. a specific order of set Q into the simulation, x the mean set-up time per product can be calculated, and hence one member of set $\mathcal{A}$ is generated. Using this procedure for a number of product streams i.e. the same mix of products in a different order, a subset of $\mathcal{A}$ is generated. The mean and standard deviation of the subset elements can be calculated and then compared with the MSTC and the SD derived from Equations 7.3 to 7.9.

7.4 Results

7.4.1 Results for System A

Equations 7.3 and 7.5 were applied to system A using the data from Table 7-1. and a simulation model of system A was also developed. To generate a set of data from the simulation model, thirty simulations were conducted, each using the same mix of parts but in a different sequence. The results from both methods are shown in Table 7-4. Detailed calculations are shown in appendix 2.

Table 7-4 Results for System A

	Mix Response Measure	Simulation Measure
MSTC in mins	5.250	5.267
SD in mins	3.437	3.443

7.4.2 Results for System B

The mix response method for measuring flexibility was applied to each of the machines in system B and the Equations 7.8 and 7.9 outlined in Section 7.2.1 were used to obtain an overall measure. The results for each machine are shown in Table 7-5.

Table 7-5 Summary of Calculations for System B

	Column 1	Column 2	Column 3	Column 4	Column 5
Mach-ine	Probability of using machine	MSTC for machine	Variance (σ^2) of MSTC for each machine	Column 1 × Column 2	Column 1 × Column 3
1	0.75	3.56	7.28	2.67	5.46
2	0.75	5.78	17.11	4.33	12.83
3	1	5.25	11.81	5.25	11.81
4	0.75	3.78	7.28	2.84	5.46
5	0.5	2.25	6.19	1.125	3.09
Sum of column 5					38.67
System SD (Sum of column 5)$^{1/2}$					6.22
System MSTC (Sum of column 4)				16.2	

A simulation model of system B was developed and thirty different sequences of parts were input into it. Table 7-6 shows a comparison of the results obtained from the simulation and the calculations shown in Table 7-6.

Table 7-6 Results for System B

	Mix response measure	Simulation measure
MSTC in mins	16.21	16.10
SD in mins	6.22	7.38

7.4.3 Results for System C

The method for measuring mix response flexibility was applied to system C and a simulation model was developed. 30 different sequences of product were used with the simulation. The results for the individual machines are shown in Table 7-7, and a comparison between the mix response measure and the simulation measure is shown in Table 7-8.

Table 7-7: Summary of Calculations for System C

	Column 1	Column 2	Column 3	Column 4	Column 5
	Probability of using machine	MSTC for machine	Variance (σ^2) of MSTC for each machine	Column 1× Column 2	Column 1 × Column 3
A	0.75	3.41	7.55	2.56	5.66
B	0.75	5.33	18.67	4	14
C	1	4.48	10.33	4.48	10.33
D	0.75	3.63	7.49	2.72	5.62
E	0.5	1.69	5.59	0.84	2.80
Sum of column 5					38.406
System SD (Sum of column 2)$^{1/2}$					6.20
System MSTC (Sum of column 4)				14.60	

Table 7-8 :Results for System C

	Mix response measure	Simulation measure
MSTC in mins	14.60	14.66
SD in mins	6.20	7.27

7.5 Validation of Results

Two methods of validation are used for the results obtained from the mix response measure. The first method is face validity (Robinson 1994) which is to examine the output of the mix response measure in terms of what should be estimated or expected. The second method is comparison with the results generated from simulation models as identified in Section 7.3.

7.5.1 Face Validity

Examining the outputs in terms of what would be logically expected is an acceptable method of face validation. In this respect, examining the results from Table 7-4, a MSTC of 5.25 minutes is slightly lower than might be expected as the mean of the set-up times for the product types k to m is 7 minutes. However, when it is considered that there will be occasions when no set-ups occur, such as when two products are manufactured sequentially, then it could be anticipated that the mean set-up time per product (MSTC) would be lower than 7 minutes. This validation technique can be extended to include using input data which would provide an obvious output. For example if the set-up time is zero for all products then the system has infinite mix response flexibility. Using this method, substituting into Equation 7.3 the expected result of zero for MSTC is obtained, which represents infinite mix response flexibility.

7.5.2 Comparison of Mix Response Flexibility with Simulation Results

The purpose of generating data from the manufacturing simulation is to allow validation of the mix response flexibility measure. To validate the measure it is necessary to prove that differences between output data from the simulation and the mix response flexibility measure, are insignificant. This can be achieved using an hypothesis test, a z-test is used for comparison of means and an F-test for comparison of SD's. The z test is a follows:

$$z = \frac{(\bar{x}_1 - \bar{x}_2) - \delta}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \qquad \text{equation 7.12}$$

Where:

$\bar{x}_1$ = the mean of population 1,

σ_1= the standard deviation of population 1,

n_1 = the size of population 1,

$\bar{x}_2$ = the mean of population 2,

σ_2= the standard deviation of population 2,

n_2 = the size of population 2, and

δ = the intended difference between the mean of population 1 and population 2, in this case 0.

In order to accept the null hypothesis that there is no significant difference between $\overline{x}_1$ and $\overline{x}_2$, at a confidence level of 0.05, z must satisfy the following conditions:

$-1.96 \leq z \geq 1.96$

For the hypothesis test on the standard deviation of the results, the F test is as follows:

$$F = \frac{\sigma_1^2}{\sigma_2^2} \text{ or } F = \frac{\sigma_2^2}{\sigma_1^2} \text{ such that } F<1$$

In order to accept the null hypothesis that there is no significant difference between the standard deviations at a confidence level of 0.01, F must satisfy the following condition:

$$F < \text{Critical value for F}$$

The critical value for F is specified by standard statistical tables and depends on the degrees of freedom for each sample.

Table 7-9 shows the results for z test for systems A, B and C. The null hypothesis can be accepted for all the systems, hence the differences between the means can be considered insignificant.

Table 7-9: "z" Test Results

	Population values	$\bar{x}_1 - \bar{x}_2 =$	$\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$	z =	Can null hypothesis be accepted ?
System A	Mix response flexibility, n = ∞ Simulation, n = 30	0.017	0.629	0.027	Yes
System B	Mix response flexibility, n = ∞ Simulation, n = 30	0.115	1.348	0.085	Yes
System C	Mix response flexibility, n = ∞ Simulation, n = 30	0.066	1.7618	0.038	Yes

The calculations for the F test are shown below in Table 7-10. From this data it can be seen that the differences between the standard deviations of the groups of data can be considered insignificant.

Table 7-10: "F" Test Results

	Critical value of F	$F = \frac{\sigma_1^2}{\sigma_2^2}$ or $F = \frac{\sigma_2^2}{\sigma_1^2}$	Can null hypothesis be accepted?
System A	1.7	1.005	Yes
System B	1.7	1.412	Yes
System C	1.7	1.376	Yes

Section 7.5.2 therefore demonstrates that there are no significant differences between the measure for mix response flexibility and the simulation results. This further validates the mix response flexibility measure.

8. INDUSTRIAL APPLICATION

The purpose of this chapter is to examine the industrial application of the conceptual model outlined in Chapter 5, and to demonstrate that measures for product flexibility and mix response flexibility can be applied in industry. Successful industrial application of the methodology will demonstrate whether the aims 1, 3 and 5 identified in section 1.5, can be achieved i.e. that

1. The data for the input values must be easy to obtain
2. Methodology must be easy to use
3. The measure must be able to assess flexibility across a range of industries

In order to demonstrate the ability to measure across a range of industries it is important to apply the model and measurement methods in different types of company. Thus Bostik Ltd and Richard Kimbell Ltd were selected for their contrasting manufacturing environments.

Bostik Ltd. manufactures sealants and adhesives and is part of a large chemical and petrochemical group, Total Ltd. Bostik's product range is relatively stable and is manufactured on a high volume flow line that consists of up to seven stages of manufacture.

Richard Kimbell Ltd is an owner managed private company, which produces a wide range of pine furniture mainly for export or for sale in its own retail outlets. The product range is constantly changing and is manufactured in small batches.

8.1 Bostik Ltd.

Bostik is a manufacturer of adhesives and sealants for both the industrial and consumer markets. It has an annual turnover of £22m and employs 180 people. Consumer products include Blu-tack, the All-Purpose adhesive range and glue-sticks. Industrial sectors served include footwear, automotive and the construction industries. Major manufacturing activities include the chemical reaction of polymers and polyesters, mixing and extrusion of sealants and packaging of consumer products.

8.1.1 Manufacturing Processes

The manufacturing process shown in Figure 8.1 can be divided into three main stages, react, crystallise and form. The first stage reaction, is carried out within three alternative reactors 2tonA, 2tonB and Mowlem. At this stage the materials that make up the product are combined by chemical reaction in the controlled environment of an enclosed reactor. Reacted products are then either decanted into drums if they are sold as liquids, or crystallised if they are sold as solids. Varying crystallisation rates are available due to a range of temperature controlled environments. The final stage is forming into reels, granules or chips. In addition, a proportion of granulated material may be further processed, by extrusion and then reeled or chipped.

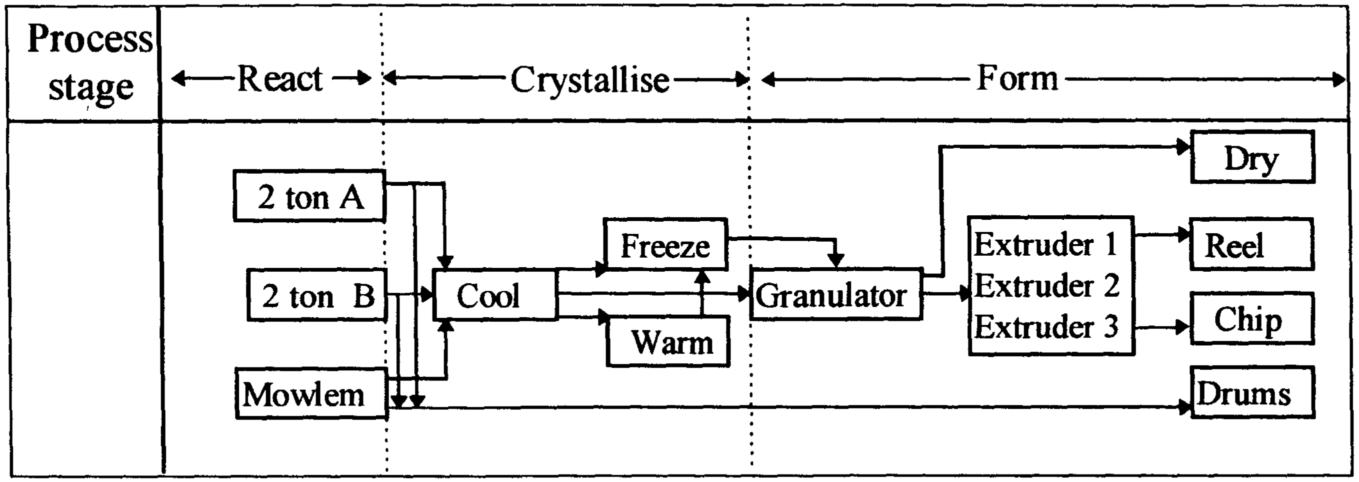


Figure 8.1 Summary of Bostik Processes

Set-ups occur when there is a need to clean out process machinery between different products, in order to reduce cross contamination between products. The equipment that requires cleaning are the reactors and the extruder. Traditionally products were processed in long product runs due to the long set-up times associated with cleaning out between products.

8.1.2 Conceptual Model Applied to Bostik Ltd

The conceptual model applied to Bostik Ltd is influenced by the cost and life of plant equipment in the chemical processing industries. Plant equipment of this type tends to have a high initial cost, but a long operational life (Walters 1997). This results in the difference between the cost of "B" cells and "C" cells which is greater than the difference in other industries. This is reflected by the relative sizes of area α_b and α_c shown in Figure 8.1. Within Bostik Ltd "B" cells represent small to medium cost changes to the plant processing equipment such as changing a valve type. The "C" cells represent medium to high cost changes such as changing the type of reactor vessel, or replacing the type of heating process.

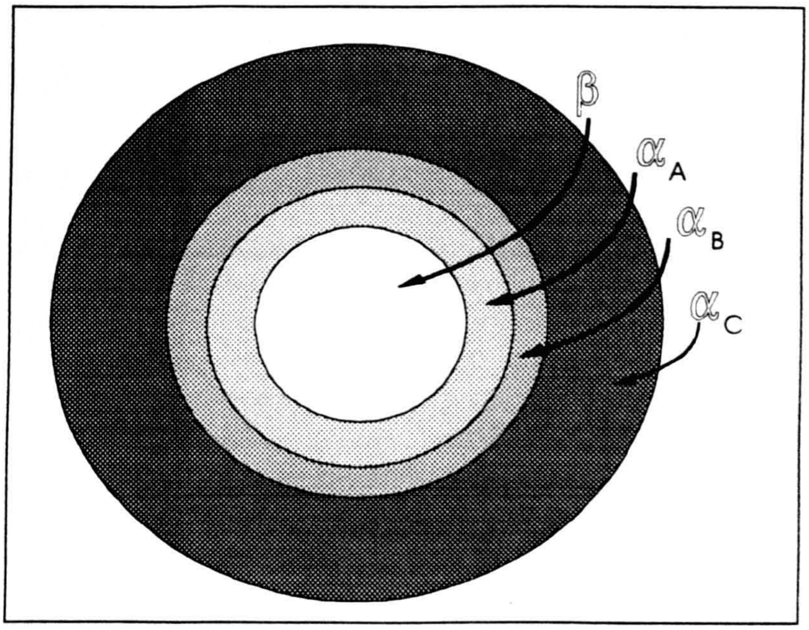


Figure 8.2: Conceptual Model of Bostik Ltd

8.1.3 Calculation of Mix Response Flexibility

Results were calculated for each stage of the production process in which a set-up occurs i.e. the reaction stage and the extrusion stage. To calculate the MSTC and the SD for each process Equations 8.3 and 8.5, shown below, have been used.

$$MSTC = \sum_{i=1}^{i=n} P_i(1 - P_i)dur_i \qquad \text{Equation 8.3}$$

$$\sigma = \sqrt{\sum_{i=1}^{i=n} (dur_i - MSTC)^2 P_i(1 - P_i)} \qquad \text{Equation 8.5}$$

Where:

P_i = the probability of a product i occurring,

dur_i = the duration of the set-up for product i , and

n = the number of different products.

In order to evaluate the components of these equations it is necessary to obtain the duration of each set-up and the probability of each product occurring. At Bostik the probability of occurrence of products was obtained from manufacturing data collected over a period of two months, this period represented a typical production cycle. Set-up duration data for the reactors was obtained from existing process information.

The data for set-up durations for the extruders was more complex. This is because the duration of the set-up procedure for a product is influenced by the chemistry of the previous product. At Bostik Ltd there are two types of product manufactured, polyesters and polyamides. A table showing the set-up times from one type of product to another is shown in Table 8-1.

Table 8-1: Set-up Durations on Extruders

To / From	Polyester	Polyamide
Polyester	0.75 hrs	2 hrs
Polyamide	1 hrs	0.75 hrs

Thus a single value of dur_i cannot be specified for product i, therefore it was necessary to take into account two possible values of dur_i when calculating the MSTC and SD. This was achieved by calculating both the probability that a specific product will be preceded by a polyamide and calculating the probability that the same product will be preceded by a polyester. This method is equivalent to treating a single product as two separate products. The calculations for this method are shown in Appendix 3.

It can be seen from Figure 8.1 that the reactors 2tonA, 2tonB and Mowlem process are in parallel, and thus the data from these items of equipment needs to be combined to obtain a MSTC and SD for this stage in the process. Similarly after the crystallisation, parallel processes occur. To combine data from parallel processes Equations 8.8 and 8.9 are used.

$$MSTC_T = \sum_{j=1}^{j=m} P_j MSTC_j \qquad \text{Equation 8.8}$$

$$SD_T = \sqrt{\sum_{j=1}^{j=m} P_j SD_j^2} \qquad \text{Equation 8.9}$$

Where:

m = number of parallel machines,

$MSTC_j$= the mean sensitivity for machine j,

SD_j = the standard deviation for STC for machine j,

$MSTC_T$ = the mean sensitivity for the parallel system,

SD_T = the standard deviation for STC for the parallel system, and

P_j = the probability of a machine j being used for a part.

Thus applying equation 8.8, at the reaction stage, the number of parallel machines m, three. The data for $MSTC_j$ and SD_j is shown in Table 8-2. The probability P_j can be calculated using the number of batches that pass through each individual machines. Thus the probability that the 2tonB reactor will be used is 0.26 i.e. number of batches that go through the machine divided by the total number of batches. With this data the $MSTC_T$ can be calculated for the reaction stage. A similar approach needs to be taken with the extruder except that as no set-up occurs in the alternative route all that is required it to multiply the machine MSTC and the variance by 0.27 (P_j the probability that a product will go through each extruder).

Table 8-2 provides a summary of the calculations for the system MSTC and SD with Appendix 3 providing details of these calculations. From the table it can be seen that the MSTC for the manufacturing system at Bostik is 2.952 hours and the SD is 3.581 hours. This is a relatively low value when compared to the overall product processing times which are of several days duration.

Table 8-2 Results for Mix Response Flexibility for Bostik Ltd

	Column 1	Column 2	Column 3	Column 4	Column 5
Machine	$MSTC_j$ in hours	SD_j in hours	P_j	$MSTC_j \times P_j$	$(SD_j)^2 \times P_j$
Mowlem	3.880	4.511	0.61	2.366	12.410
2tonB	1.243	1.087	0.26	0.318	0.303
2tonA	0	0	0.13	0	0
Extruder 1	0.998	0.646	0.27	0.268	0.112
Extruder 2	0.998	0.646	0.27	0.268	0.112
Extruder 3	0.998	0.646	0.27	0.268	0.112
System SD (Sum of column 5)$^{1/2}$ in hours					3.581
System MSTC (sum of column 4) in hours				2.952	

8.1.4 Calculation of Product Range Flexibility

The product flexibility matrix is shown in Table 8-3. The product is described in terms of the batch volume to be manufactured, the viscosity and the form. Using the method outlined in Chapter 7, Table 8-4 has been generated which shows the Total Response Cost for the system is £128,000. To calculate this value A's are costed at zero, B's are costed at £500 and C's at £10,000. The value of n/a cells was zero. The values for A changes, B changes and C changes were derived from the estimated average cost of implementing changes within each of the categories.

Table 8-3: Bostik Product Range Matrix

Equipment	Volume output in tonnes					Viscosity in poise			Form				
	0 - 0.5	0.5-1	1-2	2-3	3 - 4	20-200	200-1000	1000-50,000	liquid	block	reeled	granulated	pellets
Mowlem	C	B	B	A	C	A	A	A	A	A	A	A	A
2TA	B	A	A	B	C	A	A	C	A	A	A	A	A
2TB	B	A	A	C	C	A	A	C	A	A	A	A	A
Granulator 1	A	A	A	A	A	n/a	A	C	n/a	n/a	A	B	A
Granulator 2	A	A	A	A	A	n/a	A	C	n/a	n/a	A	B	A
Granulator 3	A	A	A	A	A	n/a	A	C	n/a	n/a	A	A	A
Extruder 7	A	A	A	A	A	n/a	A	B	n/a	n/a	A	n/a	A
Extruder 8	A	A	A	A	A	n/a	A	B	n/a	n/a	A	n/a	A
Extruder 9	B	B	B	A	A	n/a	A	B	n/a	n/a	A	n/a	A
Reeler 7/8	A	A	A	A	A	n/a	A	A	n/a	n/a	A	n/a	n/a
Reeler 9	A	A	A	A	A	n/a	A	A	n/a	n/a	A	n/a	n/a
Chipper big	A	A	A	A	A	n/a	A	B	n/a	n/a	n/a	n/a	A
Chipper sm	A	A	A	A	A	n/a	A	B	n/a	n/a	n/a	n/a	A
Dryer	A	A	A	A	A	n/a	A	A	n/a	n/a	n/a	n/a	A
Hot Room	A	A	B	C	C	n/a	A	A	n/a	A	A	A	A
Cold Room	A	A	A	A	A	n/a	A	A	n/a	A	A	A	A
Trays	A	A	A	A	A	n/a	A	A	n/a	A	A	A	A

Table 8-4: Calculations for Product Flexibility at Bostik Ltd.

Category of cell	No. of each category of cell	Cost per cell (£'s)	Cost for each category of cell (£'s)
A's	145	0	0
B's	16	500	8,000
C's	12	10,000	120,000
n/p cells	0	not specified	0
n/a cells	52	0	0
Total Response Cost			£ 128,000

8.2 Richard Kimbell Ltd

Richard Kimbell Ltd. manufactures a wide range of wooden furniture and has a sales turnover of £6m and a workforce of 150 people. Much of the product is for export, principally to the USA and Japan, and distributed via prestigious department stores and interior design companies. Domestic sales are largely through the company's own retail outlets, with a small amount being sold through department stores. For the company to maintain its competitive edge it is essential to be able to introduce new product designs quickly and economically.

8.2.1 Manufacturing Processes

A flow diagram of the manufacturing processes at Richard Kimbell's is shown in, Figure 8.3.

Table 8-5 provides details of the functions of each machine. The processes shown in Figure 8.3 essentially convert rough sawn pine planks into a variety of components that are subsequently assembled into a range of finished products.

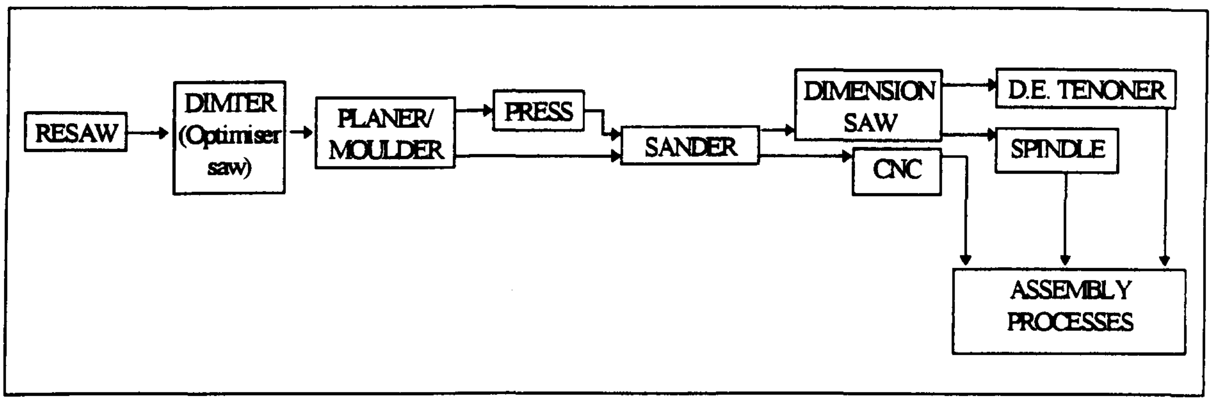


Figure 8.3: Manufacturing Processes at Richard Kimbell's

Table 8-5: Summary of Processes at Richard Kimbell Ltd

Machine	Function	Comments
Resaw	Cuts wood to four inch widths	Manual saw with vary little process variety
Dimter	Cuts wood to approximate length and reject unusable sections	Optimises use of material by minimising waste due to unusable lengths or defects in the wood. Detecting flaws and fits in pre-programmed lengths around these limitations. This has the effect of cutting many different components for different products at once.
Planer/ moulder	Planes to thickness and width of wood, cuts linear features	Uses up to five rotating drum shaped cutters to remove waste material. To achieve different shapes and sizes the cutters have to be changed and set at the appropriate position.
Press	Glues together sections of wood to make panels	The process involves applying adhesive to the wood, assembling the pieces, and the assembled component going through the press, which also cures the adhesive.
Sander	Provides good surface finish, sands to exact thickness	The sander has two sets of sanding belts. The first is very coarse, the second belt is changed between medium and fine sanding for every component.
Dimension Saw	Cuts components to exact length	A simple disk cutter, with an adjustable guide to allow accurate lengths to be cut
CNC	Cuts complex shapes and adds any features such as grooves and holes	Has a number of heads and a tool turret where different cutting tools are stored. The wood is however held on specially made beds, that need to be changed for each different component.
D.E. Tenoner	Produces a tenon joint at one or both ends	
Spindle	Adds any linear features that cannot be done on the planer moulder	

With respect to Figure 8.3 it can be seen that all components pass through the first three processes i.e. resaw, Dimter and planer/moulder. Once the components are cut, using the Dimter, they are grouped together such that all components for a product batch are then moved together through the remaining processes as a single entity. A proportion of components use the press, then all components must be sanded. After the sander, product's process routes vary according to the design of the product.

8.2.2 Conceptual Model Applied To Richard Kimbell Ltd

Richard Kimbell's market position strongly influences the flexibility of their manufacturing system. This is shown by the conceptual model of the manufacturing system shown in Figure 8.4. The area α_A is large compared to the current product range. However, the product ranges beyond α_A, i.e. α_B and α_C are not significantly larger that α_A. This is a deliberate strategy on behalf of the management team at Kimbell's adopted because the product is in a market in which changes occur quickly; they are effectively in the "fashion" sector of the furniture market. Hence there is a strong need in the design of products to reflect changes in styles of interior design, driven by the "lifestyle" magazines such as "Country Living" or "Interiors". To meet this need for rapid change, the company attempt to anticipate changes to their manufacturing needs, through the purchase of machinery before it is required by a specific product.

Although this appears to be an unnecessarily costly approach, the ability to provide many variety and style changes is an important part of the company's competitive strategy. In the medium to long term there is little redundancy in the manufacturing system since the current product range changes so frequently that all design change potential in the manufacturing system, i.e. the difference between area β and α_A, is utilised.

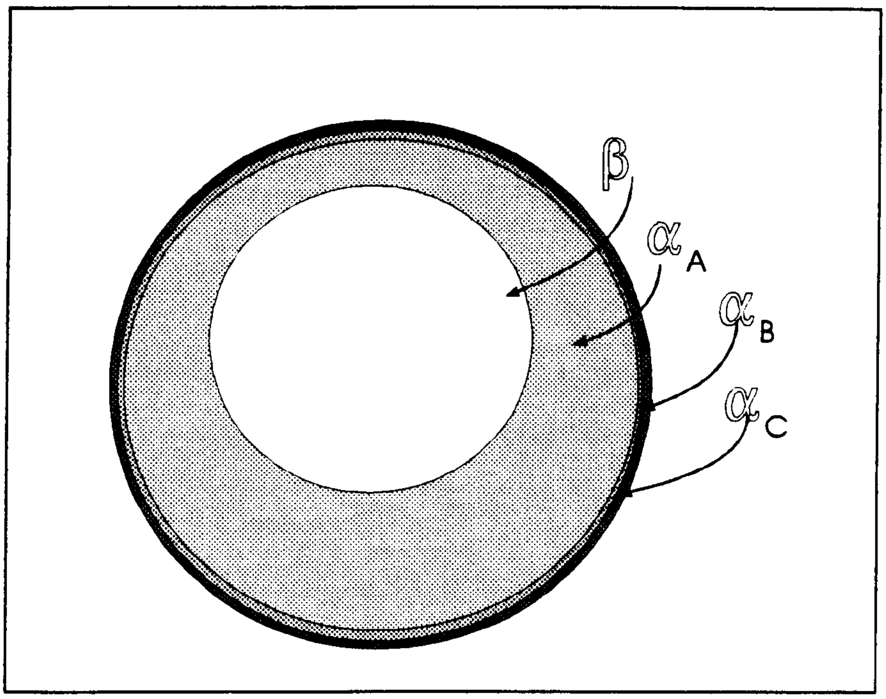


Figure 8.4: Conceptual model of Richard Kimbell Ltd

8.2.3 Calculation of Mix Response Flexibility

To calculate the mix response flexibility there is a need to determine the probability of a product or component being manufactured and the duration of set-ups at each of the items of process equipment. Since all the manufactured components are made from the same raw material, there is little component differentiation in the early stages of the manufacturing process. Hence on the resaw and Dimter, individual components are not processed separately, i.e. components are processed in groups, so set-up times of these groups need to be identified. As the components become more diverse, set-up times for individual products at each of the processes needs to be identified.

Shown in Table 8-6 are the set-up procedures for each machine, and component groups for each machine where appropriate are identified. Several of the machines require an identical set-up procedure, irrespective of the component or product for which the set-up is being performed, for example the set-up procedure on the sander is to change the sanding belt for each new product, and therefore dur_i is constant for this machine.

Table 8-6: Set-up Procedures at Richard Kimbell's

Machine	Function	Set-up procedure	Groups classified by:
Resaw	Cuts to correct width, from 8" to 4".	Sets-up for different wood widths and thickness.	Thickness
Dimter	Saws wood into approximate length	Download program and set for thickness.	Thickness
Planer/ moulder	Cuts to exact width and approximate thickness Puts in linear mouldings	Set cutters to correct position. Change cutters as required.	Width, thickness and linear shape
Press	Presses wood planks together to make large panels	Need to set width and thickness	Width and thickness
Sander	Abrades to desired surface finish	Change over sanding belts.	No groups, each product considered separately
CNC	Drills holes and cuts complex shapes	Set beds and download program	No groups, each product considered separately
Dimension saw	Cuts wood to accurate length	Set cutter guide	Length
Double End Tenoner	Cuts rails to length and shapes ends	Set length and cutter	No group, each product considered separately
Spindle	Alternative to planer/moulder can also cut angled work	Set cutter	No group, each product considered separately

To calculate the probability of occurrence of individual components or component groups, a historical list of products produced over a 120 day period was used

(Appendix 3). From this list, an extract of which is shown in Table 8-7, the probability of occurrence of each of the products was calculated.

The individual components that make up each product, can be identified from a cutting list for the product. A cutting list identifies the components, specifies their size and details manufacturing notes. Thus a cutting list performs the role of a parts list and process plan. An example of a cutting list is provided in appendix 3.

Table 8-7 Extract from the Master List of Products Manufactured

No	Code	Description	No. manufactured	% probability of occurrence
1	C-PAFF 03	small b'case front frame	17	1.164
2	C-PAFF04	wide b'case front frame	29	1.986
3	C-Q1070T	Quebec f/h top 5'x35"	18	1.233
4	C-Q1080T	Quebec f/h top 6'x35"	16	1.096
5	ENIGMA 02	lamp table 20"x20"	4	0.274
6	K-AFHB	farm house base arhous	30	2.055
7	KR-430007	Console	30	2.055
8	KR-430014	cricket table wax	40	2.740
9	KR-430095	wash stand	20	1.370
10	KR-430151	leather top writing table	1	0.001
11	KR-430185	cabriole leg end table	11	0.753
12	KR-430214	triangle	12	0.822

Using the probabilities of the products from the master list of products manufactured, the component groups identified in Table 8-6 and the cutting lists, it is possible to identify the probability of occurrence of each component group or product. This was performed for each of the machines in the manufacturing process.

Once the set-up times for each machine have been identified, and the probability of a product or product group has been established, the MSTC for each machine can be calculated. Table 8-8 shows a summary of the calculations for each machine.

Table 8-8: MSTC and SD for each of the Richard Kimbell Machines

Machine	Machine MSTC in minutes	Machine SD in minutes	Data for whole product set?	Calcs	System MSTC in mins	System SD in mins
Resaw	2.1	1.7	No for thickness groups	multiply mean and var by 1.190	2.5	1.9
Dimter	2.8	2.3	No for thickness groups	multiply mean and var by 1.190	3.3	2.5
Planer/ moulder	25.2	17.7	Yes	None required	25.2	17.7
Press	4.0	2.7	No for subset	No. going through 1431	3.8	2.7
Sander	12.0	0.7	Yes	None required	12.0	0.7
CNC	34.4	14.7	No for subset	No. going through 1174	27.2	13.0
Dimensi on saw	21.0	18.1	Yes	None required	21.0	18.1
Double End Tenoner	45	13	No for subset	No. going through 137	4.2	4.0
Spindle	9.6	8.0	No for subset	No. going through 353	2.3	3.9
				TOTAL	101.5	29.3

To calculate the total set-up time per product for the system it is necessary to convert the data from individual machines to data for the whole manufacturing system. It is necessary to categories machines into three different groups and take different approaches accordingly.

Group 1: Machines through which all products have at least one component processed i.e. planer/moulder, sander and dimension saw. As all products have at least one component which goes through these machines the machine data can be used directly for the system data.

Group 2: Machines where products are not identified separately, but specified in groups i.e. resaw and Dimter. The data from these two machines represents the MSTC and SD per thickness group, this has to be converted into MSTC and SD per product. This can be achieved by knowing the mean number of thickness groups per product which is 1.19.

Group 3: The remainder of the machines, i.e. press, CNC machine, D.E. Tenoner and spindle all process a subset of products. Therefore Equations 8.8 and 8.9 for parallel machines can be used.

Table 8-8 shows a summary of the calculations for each machine, the details of these calculations are provided in Appendix 3. The total system results are MSTC=101.520 and SD=29.285 minutes.

8.2.4 Calculation of Product Range Flexibility

Shown below in Table 8-9 is the matrix for the product range flexibility of the manufacturing system at Richard Kimbell Ltd. In addition to the machines analysed in 8.2.3 an extra machine, the lathe, is included. This is because the lathe is not currently used but is, however, available for future use.

Table 8-9: Matrix of Product Range for Richard Kimbell Ltd

	Max. length			Form		
Machine	0-1m	1-2m	2-3m	Plank	Rotational	Flat Irregular
Resaw	A	A	A	A	A	A
Dimter	A	A	A	A	A	A
Planer/moulder	A	A	A	A	A	A
Press	A	A	B	A	A	A
Sander	A	A	B	A	n/a	A
CNC	A	A	B	A	n/a	A
Lathe	A	A	n/p	n/a	A	n/a
Dimension saw	A	A	B	A	B	n/a
Double End Tenoner	A	A	n/p	A	B	B
Spindle	A	A	A	A	A	B

Table 8-10 shows that the total response cost is £22,400, where B's are costed at £300, Cs are not costed and n/p are costed at £10,000.

Table 8-10: Calculations for Product Flexibility at Richard Kimbell Ltd

Category of cell	No. of each category of cell	Cost per cell	Cost for each category of cell
A's	35	0	0
B's	8	300	2400
C's	0	n/a	0
n/p cells	2	10,000	20,000
n/a cells	4	0	0
Total Response Cost			£22,400

9. DISCUSSION

9.1 Methodology

From the literature review four main requirements for the research emerged in order that a practical measurement of flexibility could be developed:

1. The measure should build on the existing research which defines types of flexibility and relates flexibility to manufacturing strategy. This is necessary so that the measure developed has meaning in terms of competitive advantage.
2. To ensure relevance to a wide range of industries the measure should be robust enough to be applicable to different types of manufacturing systems.
3. The measure should be simple to use or busy industrialists will not to attempt to use it, and
4. The measure should reflect the subtle nature of flexibility in manufacturing, otherwise it would not give a reliable measure .

These last two requirements are difficult to reconcile, as simplicity will tend to obliterate subtly, as identified in Chapter 4. In order to overcome these problems a two-stage approach was adopted. The first stage was a development of a conceptual model (chapter 5), the second stage was the development of two numerical methods to interpret the model. As identified in Section 5.1, using a conceptual model in conjunction with numerical assessment achieves the requirements 3 and 4 listed above. The conceptual model provides a rich picture that enables the user to express an overall view of the flexibility of the system simply. The numerical assessment then provides greater detail and that enables the user to compare the flexibility of alternative manufacturing systems.

Figure 9.1 shows how the different stages in the methodology can be applied in a company.

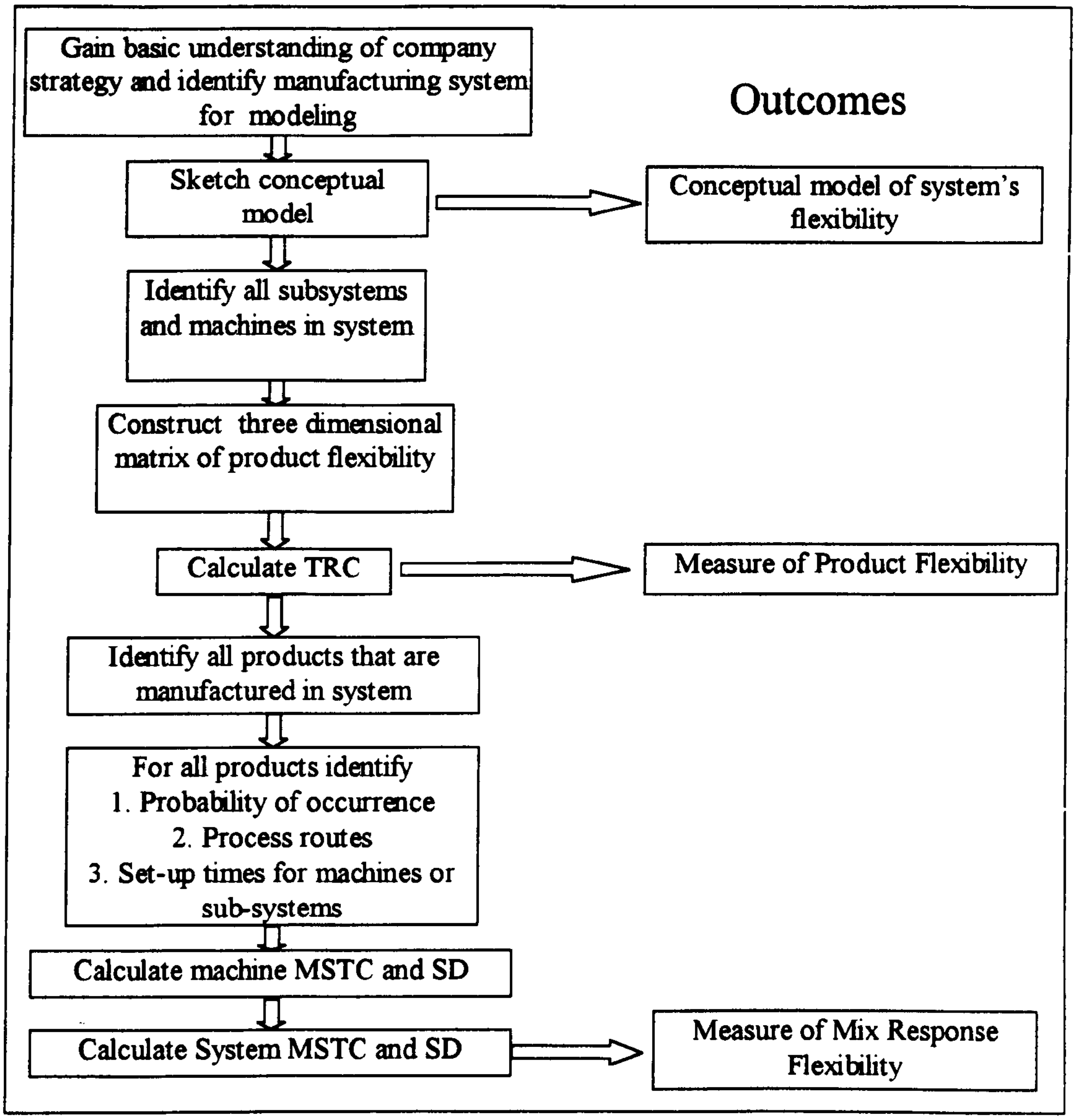


Figure 9.1 Flow diagram of measurement method within a company

In order to ensure that the flexibility methods were applicable to a wider range of manufacturing organisations, careful selection of the case study companies was necessary. In this respect the companies Bostik Ltd and Richard Kimbell Ltd were selected in order to demonstrate that the measurement methods could be applied in a range of manufacturing environments. Thus it was important that the companies adopted were different from each other, and were representative of major sectors of manufacturing industry. In this respect there were three main areas in which the companies differed:

1. Industrial sector. The case study companies were taken from two different industrial sectors. Bostik is in the sector defined by the Department of Trade and Industry as "*extraction and processing of chemicals and ores*" which represents approximately 20 % of UK manufacturing industry (HMSO 1992). Richard Kimbell is in the sector defined as "*other manufacturing*", which includes the manufacture of domestic items including textiles and furniture. This sector represents approximately 42% of UK manufacturing industry (HMSO 1992).
2. Organisational structure. Bostik is part of a large processing group Total Ltd, whereas Richard Kimbell Ltd is a small, owner managed company.
3. Type of Manufacturing System. Bostik's manufacturing system is largely a flow line based on a product layout, whereas Richard Kimbell's is a process layout, and manufacturing in small to medium sized batches.

9.2 The Conceptual Model

The conceptual model focuses on the products a company makes i.e. mix flexibility, and the potential products a company could make i.e. product flexibility. This was done because using specific types of flexibility, in this case mix flexibility and product flexibility as defined by Slack (1990), focuses the research effort to a limited range of flexibility types and thus concurs with requirement 1 specified earlier in this section, and to aim 2 specified in Section 1.5, that a measurement method should relate to specific types of flexibility.

The conceptual model can be sketched for a company's product range and manufacturing system, in order to provide a general picture of their product and mix flexibility. Different types of industry are typified by characteristic conceptual models. This is reflected by the models developed for Bostik Ltd and Richard Kimbell Ltd. The conceptual model of Bostik Ltd, shown in Figure 8.2, is typical of chemical and other processing industries. The model reflects the long operational life and high cost of plant equipment in these types of industry. The conceptual model developed for Richard Kimbell Ltd, is characteristic for their specific strategic stance of being able to introduce new designs easily. It shows how a company in a fashionable market can focus their flexibility for competitive advantage.

The conceptual model proved a useful tool for introducing the case study companies to the concept of the different types of flexibility, since mix flexibility and product flexibility are clearly shown in the model. The model was also used for explaining the meaning of the Mean Sensitivity To Change and the Total Response Cost measures.

9.3 Product Flexibility

The TRC measure provides the system designer with the ability to differentiate in terms of product flexibility between alternative manufacturing systems. However, the process of calculating TRC, using the ratings A, B, and C is subjective. The use of ratings is, however, established in both flexibility measurement (Naik and Chakravarty, 1992 and Slagmulder and Bruggeman, 1992) and operations management in general (Stevenson 1993).

It was found when applying the product flexibility measure to Richard Kimbell Ltd and Bostik Ltd the process of categorisation of A, B and Cs to cells was best achieved by differentiating between the changes in terms of small to medium sized changes and medium to large changes, rather than setting specific financial limits. Once the TRC matrix has been completed, it is possible to estimate the cost of each of these categories. This overcame the problem of setting definite cost limits before categorising each cell, which forced the user into allocating cells into categories which although numerically correct, were conceptually incorrect i.e. it was difficult to set the correct numerical limits to reflect the A, B and C categories before the process of developing the matrix.

Greater understanding of the flexibility of the system from the calculation of TRC highlights flexibility bottlenecks. Two examples of this is shown in the Bostik Ltd matrix (Table 8-3 page 107). The first example relates to the hot room, which could only process batches of up to 1 tonne, whereas the remains of the manufacturing system, if parallel processes are considered, was able to process 2 tonne batches. In response to this analysis, the company increased the size of the hot room. Thus enabling Bostik to avoid splitting batches, this had the advantage of reducing through put time and improving process consistency through the batch.

The second example is high viscosity products. These are products that are identified as a potentially growing market. It can be seen from the matrix, in Table 8-3 that high viscosity products are generally difficult to process at all stages except crystallisation. Hence considerable investment is required if the company wishes to exploit this market. Thus the analysis required to derive a TRC value has provided Bostik Ltd with direction for future development.

The product range flexibility matrix of Richard Kimbell Ltd (Table 8-9, page 117) is simple, reflecting the clear strategic direction of being able to introduce new designs easily, identified in Section 8.2.2. It can be seen that the majority of the cells are A's, which is also represented in the conceptual model in Figure 8.4, page 112.

Table 8-9 indicates that there are few characteristics that vary, i.e. only size and form. This is because many aspects which could change are established as standard policy by the company e.g. the use of exclusively pine material.

It can be seen that for the case study companies the calculation of TRC was not used in a comparison against an alternative system, but that the process of calculating TRC gives direction for short and long term development of the manufacturing system. If an alternative system were to be considered and there was sufficient information known about its machines and subsystems, then the TRC could be used for the purposes of comparison between systems.

The TRC does not directly measure product flexibility, but measures product inflexibility. This arises because the TRC measures the cost of implementing all possible changes, hence, the higher the TRC, the lower the system flexibility. A direct measure of product flexibility can be derived using the inverse of TRC, i.e. $product\ \ flexibility = \frac{1}{TRC}$. However, by this inverse measure TRC, is directly related to a monetary value and is therefore easier to interpret in a commercial environment.

It should be noted that the TRC, measure is limited by the confidence with which predictions in the A, B and C bands can be made. In the case of both Bostik Ltd and Richard Kimbell Ltd an accuracy of between 10 to 15% can be estimated for the TRC measure. This based on the estimations of employees supplying the data for the calculations.

The TRC measure with weighting factors for important characteristics described in Section 6.4.4, no longer has significance in terms of the cost of implementing all possible changes, because the weighting factor V augments the cost categories allocated to the important characteristics beyond their true value. Also no comparison can be made between systems' product flexibilities using different weightings in their calculation. It could be considered that given the limitations in using weightings, and the difficulties manufacturers have in making future predictions about which characteristics are likely to be important (Fisher Hammond, Obermeyer, and Raman, 1994) that the use of weighting factors should be limited.

9.4 Mix Response Flexibility

The mean sensitivity to change (MSTC) is a measure of mix response flexibility. The measure for MSTC and its associated SD, developed in Chapter 7, is derived from the probability that a product will be manufactured on a machine and the time associated with setting-up for that product. Section 7.5.2 has shown that the

MSTC, if products are manufactured in a random order, is analogous to the mean set-up time per product, with the SD reflecting the distribution of mean set-up times for different orders. Hence the MSTC measure reflects the mix flexibility of the machines that make up a manufacturing system. It does not take into account the order in which the products are manufactured. In order to use this information the simplest interpretation would be to compare the MSTC and SD's of two alternative manufacturing systems, in which case the MSTC could be compared between systems and used to judge the best system to adopt in the context of other criteria such as cost and output levels.

In the absence of alternative systems, data derived from a production run can be used for a comparison between the MSTC and the mean set-up time per product. This type of comparison reveals information concerning the effectiveness of the schedule in reducing the time spent in set-up. It could be assumed that the relationship between batch size and the time spent in set-up is roughly inversely linear, hence as the Production Scheduler doubles the batch size the time spent in set-up halves. However, this linear relationship breaks down as the product range reduces, since there will be an increase in the probability of a product type occurring after the same product type. The relationship between mean set-up time and batch size will also be influenced by the level of variability of both the probabilities of occurrence and set-up times of different products. For example the reduction of the mean set-up time will be more substantial if a Production Scheduler batches together a product type with long set-up durations, as opposed to product types with equivalent batch sizes and short set-up durations. Similarly, if a Production Scheduler batches together products with a low probability of occurrence rather than a product type that occurs more frequently, this will incur a greater number of undesirable features such as variance between desired and actual delivery dates or higher stock levels.

Table 9-1 shows a comparison between the relative values of MSTC and mean set-up time per product as derived from a production schedule. This comparison allows the user to differentiate between the influence of the schedule and the influence of the set-up times of the machines.

Table 9-1: Comparison of MSTC and Mean Set-Up Times per Product

The relative value of MSTC vs mean set-up time per product	Comparisons
MSTC > mean set-up time per product	1. The scheduling system can batch products together to improve production time. 2. Batching products together may adversely affect lead times or stock levels 3. If batch sizes need to be reduced, problems with throughput levels may be incurred i.e. more production time will be dedicated to set-up durations.
MSTC≈ mean set-up time per product	1. The scheduling system does not batch products together significantly.
MSTC< mean set-up time per product	1. Split batches are incurred hence the mean set-up time per product is higher than would be expected.

A similar analysis can be performed by comparing the MSTC and the total production time. A system that has a high MSTC when compared to the production time, possesses a low mix response flexibility, when these values are reversed i.e. a system that possesses a relatively low MSTC has a high mix response flexibility. It can be anticipated that different industries could benchmark appropriate ratios of MSTC to total throughput time, to indicate high and low mix response flexibility levels of their manufacturing systems.

By examining the separate MSTC for each machine it is possible to identify those machines that contribute the most to the system MSTC, and hence most inhibit the flexibility of the system. Effort can then be focused on reducing the set-up times of these machines and thus reduce the system MSTC.

It should be noted that MSTC is similar to TRC in a measure of inflexibility, in that the higher the value of MSTC the lower the flexibility of the system.

For Bostik the calculations in section 8.1.3 show a MSTC of 3 hours and a SD of 3.6 hours. This is relatively low compared to the processing time of Bostik products which can be periods of up to several days, this is primarily due to slow reaction and crystallisation rates. The MSTC is also low compared to the variation in processing times, which can vary by up to two days. In this case the MSTC analysis was used to focus effort in improving the manufacturing system by reducing the variation in processing times, as opposed to reducing set-up times which were shown to have a negligible effect.

The results for Richard Kimbell Ltd from Section 8.2.3.1 reveal a MSTC of 101.5 minutes with an SD of 29.3 minutes. The MSTC is high in comparison to the measured average setup time per product which is approximately 13.7 minutes. This occurs because Richard Kimbell Ltd tend to manufacture in batch sizes that range from 1 to 50 products, with an average batch size of approximately 8. Manufacturing in larger batches will reduce the average setup time per product, whereas, the MSTC assumes that products are manufactured individually. Within Richard Kimbell the batch size is largely determined by customer orders, i.e. large batches are generated by orders from overseas department stores who will typically order in batches sizes of 20. Thus it can be seen from Table 9-1 that if batch sizes need to be reduced, problems with throughput levels may be incurred i.e. more production time will be dedicated to set-up durations.

Examining the machines individually, Table 8-7 (page 114) shows that the planer/moulder, CNC machine, dimension saw and the double ended tenoner have the highest MSTC. Although the double ended tenoner has the highest machine MSTC, its impact on the system MSTC is limited. However, the CNC machine, planer/moulder and the dimension saw have much greater contributions to the system MSTC. The differences between the impact of these machines on the MSTC is because of the differences in the machine's processing volume. Out of the 1480 products the CNC machine processed 1174, whereas the double ended tenoner processed 137. This type of analysis provides clear indications how improvement of the flexibility of the manufacturing system can be accomplished and since gathering this data the company has taken steps to reduce the impact of the set-up times of the CNC machine and the planer/moulder. This has been achieved by purchasing an additional CNC machine and recommissioning a disused planer/moulder. Reduction exercises were also being examined for set-up times on the planer/moulder.

The process of calculating the MSTC at Richard Kimbell Ltd highlighted two main limitations with the measurement method.

1. A high number of calculations is needed for companies with large product ranges.
2. Where it is not possible to identify separate products the required calculations have additional complexity.

The first limitation is demonstrated by the MSTC calculations for Richard Kimbell Ltd. shown in appendix 3. It can be seen that each machine requires several pages of a spreadsheet to calculate the MSTC. In compensation it should be noted that the calculations are relatively simple and the basic structure can be copied from one machine's spreadsheet to another.

The second limitation is encountered in the MSTC calculations required for the resaw and the Dimter, where products are identified in groups rather than as individuals. The data from these two machines represents the MSTC and SD for each group of products that are the same thickness. This data has to be converted into MSTC and SD for individual products. This was achieved by identifying the mean number of thickness groups per product i.e. 1.9, calculated by:

$$\text{mean number of thickness groups} = \frac{\text{the total number of thickness group occurrences, 125}}{\text{the total number of products, 106}}$$

10. CONCLUSIONS

The objectives identified in Section 1.5 have been achieved:

1. Data for input values should be easy to obtain

The data for Bostik was readily available. The data at Richard Kimbell Ltd was less available because it is a smaller company where there is less opportunity for employees to gather data. However, the type of data required was possible to obtain, given the opportunity to gather it.

(Sections 8.1 and 8.2)

2. Outputs must be meaningful

The outputs of the measurement methodology relate to the types of flexibility specified by Slack (1990).

(Section 5.4)

3. Methodology should be easy to use.

The basis of the methodology consists of simple mathematics and the methodology was applicable to both companies although interpreting what represented a product was complex for Richard Kimbell Ltd in the case of the resaw and the Dimter. It was also complex identifying the duration of a set-up for the extruders for Bostik Ltd, because of the influence on set-up times between product types.

(Sections 9.3 and 9.4)

4. Must be cheap

The use of equations and the three dimensional matrix means that no investment in software is required, although a spreadsheet program is useful for the MSTC calculations.

(Sections 6.7, 7.1, 7.2 and 9.4)

5. Be able to assess flexibility across a range of industries

The results obtained indicate that the methodology can be used in a range of industries. The difference in emphasis in the results demonstrates that it can adapt to different areas of focus in different industries.

(Section 9.4)

Therefore, it can be concluded that the aim of the thesis, to develop measures for flexibility that can be easily used in a manufacturing environment has been achieved.

11. RECOMMENDATIONS FOR FURTHER WORK

1. Characteristic conceptual models for different types of industry should be developed. This will allow companies to compare their own conceptual model to an industry standard.

2. Bench marks for different industries' ratios for:

    1. MSTC and mean set-up time per product.
    2. MSTC and total manufacturing time.

This will allow companies to assess their comparative mix response flexibility.

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Appendix 1

Calculations for total response cost.

	System X	System Y	System Z
Total number of cells	150	170	200
No. of A's	81	90	100
No. of B's	22	10	20
No. of C's	35	35	40
No. of cells that cannot be achieved	12	35	40
No. A's in Colour characteristic	14	17	15
No. B's in Colour characteristic	5	15	5
No. C's in Colour characteristic	3	5	5
No. of cells that cannot be achieved in Colour characteristic	2	0	5

	System X	System Y	System Z
Total number of cells	150	170	200
No of A's minus colour A's	81-14=67	90-17=73	100-15=85
No. of B's minus colour B's	22-5=17	10-0=10	20-5=15
No. of C's minus colour C's	35-3=32	35-10=25	40-5=35
No. of cells that cannot be achieved minus No. of colour cells that cannot be achieved	12-2=10	35-0=35	40-5=35

	Cost in £
A	0
B	1000
C	4000
criteria that cannot be achieved	10000
A in colour	0X1.2=0
B in colour	1000X1.2=1200
C in colour	4000X1.2=5000
Criteria that cannot be achieved in colour	10000X1.2=12000

	System X	System Y	System Z
Cost of A's minus colour A's	67X 0=0	73X 0=0	85X 0=0
Cost of B's minus colour B's	17X 1000= 17000	10X 1000= 10000	15X 1000= 15000
Cost of C's minus colour C's	32X 4000= 128000	25X 4000= 100000	35X 4000= 140000
Cost of cells that cannot be achieved minus No. of colour cells that cannot be achieved	10X 10000= 100000	35X 10000= 350000	35X 10000= 350000
Cost of A's in Colour characteristic	14X 0=0	17X 0=0	15X 0=0
Cost of B's in Colour characteristic	5X 1200= 6000	15X 1200= 18000	5X 1200= 18000
Cost C's in Colour characteristic	3X 5000= 15000	5X 5000=2500 0	5X 5000= 25000
Cost of cells that cannot be achieved in Colour characteristic	2X 12000= 24000	0X 12000=0	5X 12000= 60000
Total cost	290000	503000	608000

APPENDIX 2

Calculations for mix resposne flexibility System A

MSTC in minutes per product

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s . p_n(1-p_n)$
j	7	0.25	0.1875	1.3125
k	5	0.25	0.1875	0.9375
l	10	0.25	0.1875	1.875
m	6	0.25	0.1875	1.125
			total MSTC	5.25

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 . p_n(1-p_n)$
j	7	3.0625	0.1875	0.5742
k	5	0.625	0.1875	0.1172
l	10	22.5625	0.1875	4.2305
m	6	0.5625	0.1875	0.1055
all zero setups	0	27.5625	0.25	6.8906
			σ^2	11.918
			σ	3.452

Note: "All zero setups" are included in the calculation of the standard deviation STC to represent all occasions when a product type follows the same product type.

Calculations for mix resposne flexibility System B

Machine 1

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s \cdot p_n(1-p_n)$
j	5	0.33	0.22	1.1111
k	4	0.33	0.22	0.8889
m	7	0.33	0.22	1.5556
			total MSTC	3.5556

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 . p_n(1-p_n)$
j	5	2.0736	0.22	0.456192
k	4	0.1936	0.22	0.042592
m	7	11.8336	0.22	2.603392
all zero setups	0	12.6736	0.33	4.182288
			σ^2	7.284464
			σ	2.699

Machine 2

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s \cdot p_n(1-p_n)$
j	10	0.33	0.22	2.222222
l	8	0.33	0.22	1.77776
m	8	0.33	0.22	1.77776
			total MSTC	5.777742

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 \cdot p_n(1-p_n)$
j	10	17.8084	0.22	3.917848
k	8	4.9284	0.22	1.084248
m	8	4.9284	0.22	1.084248
all zero setups	0	33.4084	0.33	11.02477
			σ^2	17.11112
			σ	4.137

Machine 3

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s . p_n(1-p_n)$
j	7	0.25	0.1875	1.3125
k	5	0.25	0.1875	0.9375
l	10	0.25	0.1875	1.875
m	6	0.25	0.1875	1.125
			total MSTC	5.25

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s- MSTC)^2$	$p_n(1-p_n)$	$(dur_s- MSTC)^2 . p_n(1-p_n)$
j	7	3.0625	0.1875	0.574219
k	5	0.0625	0.1875	0.011719
l	10	22.5625	0.1875	4.230469
m	6	0.5625	0.1875	0.105469
all zero setups	0	27.5625	0.25	6.890625
			σ^2	11.8125
			σ	3.44

Machine 4

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s . p_n(1-p_n)$
j	6	0.33	0.22	1.333333
k	6	0.33	0.22	1.333332
m	5	0.33	0.22	1.11111
			total MSTC	3.78

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 . p_n(1-p_n)$
j	6	4.938283	0.22	1.097395
k	6	4.938283	0.22	1.097395
m	5	1.493833	0.22	0.331963
all zero setups	0	14.27159	0.33	4.75719
			σ^2	7.283943
			σ	2.699

Machine 5

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s . p_n(1-p_n)$
l	3	0.5	0.25	0.75
m	6	0.5	0.25	1.5
			total MSTC	2.25

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 . p_n(1-p_n)$
l	3	0.5625	0.25	0.140625
m	6	14.0625	0.25	3.515625
all zero setups	0	12.6736	0.5	2.53125
			σ^2	6.1875
			σ	2.487

Data for simulation of System 2

Replication	Duration of simulation in minutes	% of time spent in set-up at:					set-up per product in minutes
		A	B	C	D	E	
1	2816	10.26	16.62	20.03	10.55	4.79	**17.53**
2	2776	10.37	16.14	18.84	9.29	4.21	**16.34**
3	2950	8.31	16.41	18.75	8.88	4.58	**16.79**
4	2828	8.83	15.8	17.54	8.19	4.16	**15.32**
5	2880	11.6	17.71	20.14	12.5	3.12	**18.28**
6	2783	12	16.39	18.07	11.25	2.59	**16.78**
7	2777	9.61	16.2	17.97	8.93	3.89	**15.72**
8	2878	9.76	15.01	17.55	9.24	3.75	**15.92**
9	2930	8.02	14.81	18.05	9.39	2.76	**15.54**
10	2839	8.91	13.46	16.66	8.59	3.17	**14.42**
11	2837	9.62	15.44	19	9.13	4.12	**16.26**
12	2818	8.8	17.74	18.81	8.84	4.47	**16.53**
13	2814	9.45	14	17.87	9.74	3.2	**15.27**
14	2781	8.99	16.97	19.81	9.64	3.88	**16.49**
15	2905	7.71	19.14	19.79	7.95	4.03	**17.03**
16	2900	9.28	12.76	16.76	9.62	3.72	**15.12**
17	2793	9.63	16.25	19.69	9.34	4.83	**16.68**
18	2900	10.62	16	18.07	10.79	3.1	**16.99**
19	2868	7.53	13.53	17.12	8.3	3.45	**14.32**
20	2790	9.25	14.34	16.95	9.82	16.95	**15.13**
21	2882	11.21	16.24	18.53	11	3.75	**17.50**
22	2813	9.14	14.43	18.34	9.74	4.16	**15.70**
23	2856	9.31	12.32	15.23	9.59	2.21	**13.90**
24	2835	10.69	16.23	17.95	11.01	4.13	**17.01**
25	2779	12.4	13.03	19.81	9.51	3.56	**14.86**
26	2791	9.49	14.4	17.38	9.82	3.55	**15.25**
27	2842	8.48	13.09	17.1	8.97	3.17	**14.44**
28	2865	9.91	15.57	18.64	9.28	4.08	**16.46**
29	2857	10.26	15.82	17.92	10.19	4.1	**16.63**
30	2906	10.77	17.27	20.65	10.77	4.65	**18.63**
MSTC							**16.095**
SD[1]							**7.383275**

[1] this standard deviation is not calculated from the data in the "setup time per product" column because this would indicate the SD of the mean setup time per product per simulation. The SD has to be calculated using the equation 7.3 and the frequency of occurrence of the product.

Calculations for mix resposne flexibility System C

Summary of data

	machine	1	1	2	2	3	4	4	4	5	5
product		dur	p	dur	p	dur	p	dur	p	dur	p
j	0.2	5	0.2222	10	0.3333	7	0.2	6	0.2222		0
k	0.4	4	0.4444		0	5	0.4	6	0.4444		0
l	0.1		0	8	0.1667	10	0.1		0	3	0.25
m	0.3	7	0.3333	8	0.5	6	0.3	5	0.3333	6	0.75

Machine 1

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s . p_n(1-p_n)$
j	5	0.222	0.173	1.1111
k	4	0.444	0.247	0.8889
m	7	0.333	0.222	1.5556
			total MSTC	3.407

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 . p_n(1-p_n)$
j	5	2.536351	0.173	0.438
k	4	0.351166	0.247	0.087
m	7	12.90672	0.222	2.868
all zero setups	0	11.61043	0.358	4.157
			σ^2	7.55
			σ	2.748

Machine 2

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s.\ p_n(1-p_n)$
j	10	0.333	0.222	2.222
l	8	0.167	0.139	1.111
m	8	0.5	0.25	2
			total MSTC	5.333

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2.\ p_n(1-p_n)$
j	10	21.77778	0.222	4.84
k	8	7.111111	0.139	0.988
m	8	7.111111	0.25	1.778
all zero setups	0	28.44444	0.389	11.06
			σ^2	18.666
			σ	4.320

Machine 3

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s \cdot p_n(1-p_n)$
j	7	0.2	0.16	1.12
k	5	0.4	0.24	1.2
l	10	0.1	0.09	0.9
m	6	0.3	0.21	1.26
			total MSTC	4.48

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 \cdot p_n(1-p_n)$
j	7	6.3504	0.16	1.016
k	5	0.2704	0.24	0.065
l	10	30.4704	0.09	2.742
m	6	2.3104	0.21	0.485
all zero setups	0	20.0704	0.3	6.021
			σ^2	10.329
			σ	3.214

Machine 4

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s . p_n(1-p_n)$
j	6	0.222	0.173	1.037
k	6	0.444	0.247	1.481
m	5	0.333	0.222	1.111
			total MSTC	3.63

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 . p_n(1-p_n)$
j	6	5.618656	0.173	0.971
k	6	5.618656	0.247	1.387
m	5	1.877915	0.222	0.417
all zero setups	0	13.17421	0.358	4.717
			σ^2	7.492
			σ	2.737

Machine 5

MSTC

part	dur_s	p_n	$p_n(1-p_n)$	$dur_s . p_n(1-p_n)$
l	3	0.25	0.188	0.563
m	6	0.75	0.188	1.125
			total MSTC	1.688

Calculation of SD of STC in minutes per product

part	dur_s	$(dur_s - MSTC)^2$	$p_n(1-p_n)$	$(dur_s - MSTC)^2 . p_n(1-p_n)$
l	3	1.722656	0.188	0.323
m	6	18.59766	0.188	3.487
all zero setups	0	2.847656	0.625	1.78
			σ^2	5.59
			σ	2.364

Data for Simulation method system C

Replication	Duration of simulation in minutes	% of time spent in se-tup at:					set-up per product in minutes
		A	B	C	D	E	
1	2825	12.07	11.02	15.05	11.65	2.12	14.66458
2	2873	10.48	10.09	14.62	11.52	1.88	13.95991
3	2802	10.74	12.71	15.54	11.6	1.93	14.7161
4	2828	11.32	13.37	15.7	11.21	2.23	15.22312
5	2927	9.05	9.5	15	10.04	2.15	13.3881
6	2889	11.01	10.87	14.92	11.35	1.87	14.45078
7	2848	11.45	11.1	15.34	11.55	2.21	14.70992
8	3020	10.33	11.59	16.62	11.89	2.68	16.03922
9	2930	9.38	10.44	14.33	10.41	2.76	13.86476
10	2900	13.41	12.14	16.45	13.41	1.86	16.6083
11	2933	10.48	10.6	14.83	10.74	2.45	14.40103
12	2833	10.48	9.78	9.16	13.35	1.46	12.53036
13	2889	12.18	12.81	17.2	12.18	2.8	16.51641
14	2884	10.02	10.06	15.19	10.92	1.87	13.8605
15	2691	10.48	8.55	15.61	10.03	3.01	12.83069
16	2881	10.97	10.76	14.14	11.18	1.56	14.00454
17	2819	10.32	11.14	15.25	9.97	2.23	13.78773
18	2878	10.74	10.91	15.15	10.7	2.81	14.47922
19	2846	10.75	13.07	18.1	11.98	3.16	16.23928
20	2908	9.15	12.38	18.19	11.11	2.17	15.4124
21	2828	11.41	13.6	15.76	10.38	2.55	15.18636
22	2942	10.84	10.13	15.84	11.05	1.84	14.62174
23	2779	10.33	11.44	15.19	9.75	3.24	13.88111
24	2893	11.23	8.5	14	12.24	1.45	13.71861
25	2943	12.4	10.6	13.93	12.3	1.12	14.81801
26	2863	10.09	11.25	15.51	10.69	2.83	14.42093
27	2790	11	10.32	15.38	11.22	1.94	13.91094
28	2871	12.47	11.77	15.05	11.74	1.25	15.00959
29	2825	9.35	10.69	14.83	10.87	2.55	13.64193
30	2890	13.01	9.97	15.36	12.32	1.87	15.18117
MSTC							14.53591
SD							7.270046

APPENDIX 3

Batch	Item	Job No.	Quantity
	WASHSTAND	KR-430095 LANE: 26	

Done	Description	No. of Pieces	Finished Sizes L	Finished Sizes W	Finished Sizes T	Remarks	Timber
	TOP *	1	610	460	20	EQUAL OVERHANG	
	FRONT RAIL	1	470	120	20	BK + FT	
	BACK RAIL	1	470	120	20		
	SIDE RAILS	2	315	120	20		
	Bot Front Rail	1	470	32	20		
	Bot Back Rail	1	470	32	20		
	Bot Side Rails	2	315	32	20		
	SHELF *	1	550	400	15		
*	GALLERY						
	SIDES	2	475	85	15		
	BACK	1	610	120	15		
*	LEGS	4	707	40	40		

Washstand

Master List of Products Manufactured at Richard Kimbell Ltd

No	Code	Desc.	No.	% prob.	No.	Code	Desc.	No.	% prob.
1	C-PAFF 03	small b'case front frame	17	1.164	54	KR-NOVAQ	nova bed 5'	10	0.685
2	C-PAFF04	wide b'case front frame	29	1.986	55	KR-NOVAS	3' nova bed	6	0.411
3	C-Q1070T	Quebec f/h top 5'x35"	18	1.233	56	KR-PAO2	panel 2 drawer bedside	14	0.959
4	C-Q1080T	Quebec f/h top 6'x35"	16	1.096	57	KR-PA05	panel 2 drawer sidetable	6	0.411
5	ENIGMA 02	lamp table 20"x20"	4	0.274	58	KR-PA12	2/3 chest of drawers	9	0.616
6	K-AFHB	farm house base arhous	30	2.055	59	KR-PA21	1 door wardrobe	10	0.685
7	KR-430007	Console	30	2.055	60	KR-PA22	2 door wardrobe	13	0.890
8	KR-430014	cricket table wax	40	2.740	61	KR-PA23	3 door wardrobe	30	2.055
9	KR-430095	wash stand	20	1.370	62	KR-PA24	4 door wardrobe	44	3.014
10	KR-430151	leather top writing table	1	0.001	63	KR-PA30	panel corner cupboard	6	0.411
11	KR-430185	cabriole leg end table	11	0.753	64	KR-PA35	gents wardrobe	12	0.822
12	KR-430214	triangle	12	0.822	65	KR-PA40	panel wellington chest	10	0.685
13	KR-430286	astragal bookcase	21	1.438	66	KR-PA50	panel open top bside/video	14	0.959
14	KR-AL19	19 drawer chest	20	1.370	67	KR-PABC01	panel b'case 1962x305	23	1.575
15	KR-BALL01	gothic dresser + locks	1	0.068	68	KR-PABC02	panel b'case 40x48x16.5	17	1.164
16	KR-OBOX02	blanket box 24"	13	0.890	69	KR-PABC03	panel b'case narrow	32	2.192
17	KR-OBOX03	ottoman 36"	11	0.753	70	KR-PABC04	panel b'case 82x49x17.5	34	2.329
18	KR-OBOX04	ottoman 54"	10	0.685	71	KR-PBS	pot board server	9	0.616
19	KR-CD01	computer cupboard	17	1.164	72	KR-PTBS	butterfly table 5x 37.5	3	0.205
20	KR-COBC01	corbel cupboard	13	0.890	73	KR-PTBT	butterfly table 6'	3	0.205
21	KR-CTBA3	barley coffee 36"x24"	27	1.849	74	KR-Q1190T	48" round table top	6	0.411
22	KR-CTB3	barley coffee 42"x30"	29	1.986	75	KR-Q1406	small bookcase	16	1.096
23	KR-CTBF	barley coffee 4'x3'	11	0.753	76	KR-QHTOP60	f/h top thick 5'x35"	61	4.178
24	KR-CTUSA3	qebec coffee table 36x24	17	1.164	77	KR-QHTOP72	f/h top 6'x35"	25	1.712
25	KR-CTUSAC3	qebec coffee table 42x30	36	2.466	78	KR-QDGB4	quebec gothic 4 dr base	4	0.274
26	KR-CTUSF3	qebec coffee table 48x36	19	1.301	79	KR-QGR3	open gothic rack	9	0.616
27	KR-BED1	daybed 4'6"	4	0.274	80	KR-QGT3	glazed rack 3 door	5	0.342
28	KR-BEDB1	daybed 4'6" with back	12	0.822	81	KR-RBED54	ribbon and bow bed 4'6"	7	0.479
29	KR-FH101	4'x30" f/h table	20	1.370	82	KR-RBED60	ribbon and bow bed 5'	8	0.548
30	KR-FH106	4'6"x35" f/h table	20	1.370	83	KR-RBHB60	ribbon & bow h'bd 60"	2	0.137
31	KR-FH107	5'x35" f/h table	21	1.438	84	KR-RT117	round 35" ped. table	15	1.027
32	KR-FH108	6'x35" f/h table	13	0.890	85	KR-RT118	round 42" ped table	15	1.027
33	KR-FILE2PA	2 drawer filing cabinet	24	1.644	86	KR-RT119	round 48" ped table	15	1.027
34	KR-G2DDR	gothic 2 door dresser	5	0.342	87	KR-RU	glazed corner unit rut'	10	0.685
35	KR-G3DDR	gothic 3 door dresser	5	0.342	88	KR-T102	f/h 4'6"x 3"	1	0.068
36	KR-GCC	glazed corner cupboard	2	0.137	89	KR-T103	f/h 4'6"x 2'6"	26	1.781
37	KR-GDB2	2 dr gothic dresser base	2	0.137	90	KR-T04	card table	29	1.986
38	KR-GGBC	gothic glazed book case	14	0.959	91	KR-T101	blue f/h 6'x 35"	1	0.068
39	KR-GGDR3	gothic glazed dresser	9	0.616	92	KR-TT101	tongue table4'x30"	3	0.205
40	KR-GGDR4	gothic 4 dresser glazed	4	0.274	93	KR-TT102	tongue table4.5'x30" th	3	0.205
41	KR-GRBC	gothic open bookcase	10	0.685	94	KR-TT110	tongue table5'x37"	1	0.068
42	KR-JENKINS	gothic glazed see spec	1	0.068	95	KR-TT111	tongue table6'x37" 1.5	6	0.411
43	KR -LP01L	L.P. pot cupboard	15	1.027	96	KR-TT139	tongue table6'x37" ex2"	1	0.068
44	KR-LP01R	L.P. pot cupboard	15	1.027	97	KR-TT165	8'x41" refectory table	1	0.068
45	KR-LP10	louis phillipe double cod	13	0.890	98	LANE 04	gothic dresser	10	0.685
46	KR-LP15	3+1 drawer chest	7	0.479	99	LANE27	cricket table waxed	12	0.822
47	KR-LP22	L. P. 2 door wardrobe	4	0.274	100	LANE39	astral glazed bookcase	22	1.507
48	KR-LP40	L.P. langerie c/board	5	0.342	101	LANE46	console table	1	0.068
49	KR-MUY02	quebec f/h 5" thick leg	20	1.370	102	MACY10	coffee table	59	4.041
50	KR-MUY03	quebec f/h 6" thick leg	20	1.370	103	MACY11	end table	6	0.411
51	KR-MUY04	coffee table	22	1.507	104	SOFA03	cross board table 6x44	1	0.068
52	KR-NOVAD	nova bed 4'6"	9	0.616	105	SOFA04	cross board table 7x44	2	0.137
53	KR-NOVADH	4'6" nova headboard	1	0.068	106	SOFA05	salernes bed	3	0.205

MOWLEM AND 2TONB CALCULATIONS								
Mowlem								
PROD	No.	Pn	Pn (1-Pn)	Setup dur	C5*D5			
							mean-dur^2	var
HM732	11	0.22	0.1716	2	0.3432		3.5344	0.606503
ZE47	6	0.12	0.1056	2	0.2112		3.5344	0.373233
HM5584	5	0.1	0.09	2	0.18		3.5344	0.318096
38SA869	3	0.06	0.0564	2	0.1128		3.5344	0.19934
H RESIN	3	0.06	0.0564	2	0.1128		3.5344	0.19934
38SA881	1	0.02	0.0196	2	0.0392		3.5344	0.069274
HM746	1	0.02	0.0196	2	0.0392		3.5344	0.069274
38SA871	2	0.04	0.0384	2	0.0768		3.5344	0.135721
CAPA650	18	0.36	0.2304	12	2.7648		65.9344	15.19129
total	50	zeros	0.212	0			15.0544	3.191533
				MSTC	3.88		Sigma sqr	20.3536
							sigma	4.511496
composed 13.3.96								
2tonB								
PROD	No.	Pn	Pn (1-Pn)	Setup dur	C5*D5		mean-dur^2	var
249	5	0.238	0.181	2	0.362812		0.77408076	0.140423
F RESIN	1	0.048	0.045	2	0.090703		1.32693682	0.060179
7242	2	0.095	0.086	2	0.172336		1.14553093	0.098708
7915	1	0.048	0.045	0	0		1.54413027	0.070029
DT 171	2	0.095	0.086	0	0		1.54413027	0.133054
H RESIN	6	0.286	0.204	0	0		1.54413027	0.315129
9437	4	0.190	0.154	4	0.61678		0.39168865	0.060396
TOTAL	21	zeros	0.197	0	0		1.54413027	0.304624
				mstc	1.24263			
							sigma sqr	1.182542
							sigma	1.087447

	EXTRUDER CALCULATIONS											
	Product list					POLYAIMIDES						
	Product	No. of batches	E/A	Probability				p(1-p)	dur	dur.p(1-p)	(m-x)^2	sd calcs
	HM5591	4	A	0.181818		HM5591	A to A	0.041322	0.75	0.030992	0.061471	0.00254
	HM5563	3	A	0.136364			A to E	0.107438	1	0.107438	4.27E-06	4.59E-07
	HM5558	2	A	0.090909		HM5563	A to A	0.03719	0.75	0.027893	0.061471	0.002286
	249	3	E	0.136364			A to E	0.080579	1	0.080579	4.27E-06	3.44E-07
	HM746	1	E	0.045455		HM5558	A to A	0.028926	0.75	0.021694	0.061471	0.001778
	9437	1	E	0.045455			A to E	0.053719	1	0.053719	4.27E-06	2.29E-07
	HM5539	3	E	0.136364								
	ZE47	5	E	0.227273		POLYESTERS						
	TOTAL	22										
						249	E to A	0.055785	2	0.11157	1.004137	0.056016
	Setup duration		Nos				E to E	0.061983	0.75	0.046488	0.061471	0.00381
						HM746	E to A	0.018595	2	0.03719	1.004137	0.018672
	E to A	2	Es	0.590909			E to E	0.024793	0.75	0.018595	0.061471	0.001524
	A to E	1	As	0.409091		9437	E to A	0.018595	2	0.03719	1.004137	0.018672
	A to A	0.75					E to E	0.024793	0.75	0.018595	0.061471	0.001524
	E to E	0.75				HM5539	E to A	0.055785	2	0.11157	1.004137	0.056016
							E to E	0.061983	0.75	0.046488	0.061471	0.00381
						ZE47	E to A	0.092975	2	0.18595	1.004137	0.09336
							E to E	0.082645	0.75	0.061983	0.061471	0.00508
						same prod	to same	0.152893	0		0.995872	0.152261
									mean	0.997934	var	0.417351
											sd	0.646027
							Method					
							A toA	p(P(all aimides -p)				
							A to E	p(all esters)				

	FINAL CALCULATIONS FOR BOSTIK						
		MSTC	SD	All		mean	var
	Mowlem	3.88	4.511496	No	50 shifts worth	2.365854	12.41073
	Two tonne	1.24263	1.087447	No	21 shifts worth	0.318235	0.302846
	Two tonne	0	0	No	11 shifts worth	0	0
	Barmag	0.997934	0.646027	No	22 shifts worth	0.267738	0.111972
					mean	2.951827	12.82555
						sd	3.581277

	Code	Desc.	No.	occur(p)	steup dur														
1	C-PAFF 03	small bookcase front fra	17	1.164		C-PAFF 03	1.082113	C-PAFF04	1.845958	C-Q1070T	1.145767	C-Q1080T	1.01846					ENIGMA 02	0.254615
2	C-PAFF04	wide bookcase front fra	29	1.986		length	thickness	length	thickness	length	thickness	length	thickness					length	thickness
3	C-Q1070T	Quebec farmhouse top	18	1.233		1070	1	2150	1	1600	1.5	1900	1.5					580	1
4	C-Q1080T	Quebec farmhouse top	16	1.096		940	1	1180	1										
5	COLANDE	3 Pine boards for knives	0	0.000		900	1	1135	1										
6	DIXON 01	Cd shelves sliding mech	0	0.000		1050	1												
7	ENIGMA 0	lamp table 20"x20"	4	0.274															
8	HOLDENB	shop sign	0	0.000				K-AFHB	1.909612	KR-430007	0	KR-430014	2.546149	KR-430095	1.273074	KR-430151	0.063654	KR-430185	0.700191
9	K-AFHB	farm house base arhous	30	2.055				length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
10	KR-430007	Console	30	2.055				1300	1	1520	1	780	1.5	635	1			680	1
11	KR-430014	cricket table wax	40	2.740				700	1			570	1	575	1			490	1
12	KR-430095	wash stand	20	1.370				180	1										
13	KR-430151	leather top writing table	0	0.000															
14	KR-430185	cabriole leg end table	11	0.753															
15	KR-430214	triangle	12	0.822		KR-43021	0.822	KR-43028	1.438	KR-AL19	1.370	KR-BALL0	0.068	KR-OBOX0	0.890	KR-OBOX	0.753	KR-OBOX	0.685
16	KR-430286	astragal bookcase	21	1.438		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
17	KR-AL19	19 drawer chest	20	1.370		510	1	1240	1	1870	1.25	1290	1.5	610	1	910	1	1370	1
18	KR-BALL01	gothic dresser with locks	1	0.068				1240	1	930	1	920	1	600	1	900	1	1360	1
19	KR-OBOX0	blanket box 24"	13	0.890								1135	1	340	1	450	1	450	1
20	KR-OBOX0	ottoman 36"	11	0.753												900	1	1360	1
21	KR-OBOX0	ottoman 54"	10	0.685															
22	KR-CD01	computer cupboard	17	1.164		KR-CD01	1.164	KR-COBC	0.890	KR-CTBA	1.849	KR-CTB3	1.986	KR-CTBF	0.753	KR-CTUS	1.164	KR-CTUS	2.466
23	KR-COBC0	corbel cupboard	13	0.890		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
24	KR-CTBA3	barley coffee 36"x24"	27	1.849		1770	1	2050	1	990	1.5	1140	1.5	1290	1.5	990	1	1140	1
25	KR-CTB3	barley coffee 42"x30"	29	1.986		1050	1	940	1										
26	KR-CTBF	barley coffee 4'x3'	11	0.753		450	1	900	1										
27	KR-CTUSA	quebec coffee table 36"	17	1.164		440	1												
28	KR-CTUSA	quebec coffee table 42"	36	2.466															
29	KR-CTUSF	quebec coffee table 48"	19	1.301		KR-CTUS	1.301	KR-BED1	0.274	KR-BEDB	0.822	KR-FH101	1.370	KR-FH106	1.370	KR-FH107	1.438	KR-FH108	0.890
30	KR-BED1	daybed 4'6"	4	0.274		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
31	KR-BEDB1	daybed 4'6" with back	12	0.822		1290	1.5	580	1.25	580	1.25	1290	1.5	1440	1.5	1600	1.5	1900	1.5
32	KR-FH101	4'x30" f/h table	20	1.370						1630	1.25								
33	KR-FH106	4'6"x35" f/h table	20	1.370															
34	KR-FH107	5'x35" f/h table	21	1.438															
35	KR-FH108	6'x35" f/h table	13	0.890															
36	KR-FILE2P	2 drawer filing cabinet	24	1.644		KR-FILE2	1.644	KR-G2DD	0.342	KR-G3DD	0.342	KR-GCC	0.137	KR-GDB2	0.137	KR-GGBC	0.959	KR-GGDR	0.616
37	KR-G2DDR	gothic 2 door dresser	5	0.342		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
38	KR-G3DDR	gothic 3 door dresser	5	0.342		610	1	1290	1.5	1790	1.5	1850	1.25	1290	1.5	2060	1	1300	2
39	KR-GCC	glazed corner cupboard	2	0.137		810	1	920	1	920	1			920	1	1000	1	1630	2
40	KR-GDB2	2-door gothic dresser ba	2	0.137		440	1	1135	1	1630	1			1135	1	1000	1	1630	2
41	KR-GGBC	gothic glazed book case	14	0.959		455	1									950	1		
42	KR-GGDR3	gothic glazed dresser	9	0.616															
43	KR-GGDR4	gothic 4 dresser glazed	4	0.274		KR-GGDR	0.274	KR-GRBC	0.685	KR-JENKI	0.068	KR -LP01	1.027	KR -LP01R	1.027	KR-LP10	0.890	KR-LP15	0.479
44	KR-GRBC	gothic open bookcase	10	0.685		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
45	KR-JENKIN	gothic glazed see spec	1	0.068		1300	1	2060	1	1970	1	690	1	690	1	1800	1.25	1000	1.25
46	KR -LP01L	louis phillipe pot cupboar	15	1.027		2130	1	1000	1	1000	1	650	1	650	1	950	1	1020	1
47	KR -LP01R	louis phillipe pot cupboar	15	1.027		1080	1	1000	1	1000	1	570	1	570	1				
48	KR-LP10	louis phillipe double cod	13	0.890		1260	1	950	1	1000	1	500	1.25	500	1.25				
49	KR-LP15	3+1 drawer chest	7	0.479															
50	KR-LP22	louis phillipe 2 door war	4	0.274		KR-LP22	0.274	KR-LP40	0.342	KR-MUY0	0.342	KR-MUY0	1.370	KR-MUY04	1.507	KR-NOVA	0.616	KR-NOVA	0.068
51	KR-LP40	louis phillpie langerie c/b	5	0.342		length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
52	KR-MUY02	quebec f/h 5" thick f/h le	20	1.370		1970	1	750	1	1592	2	1900	2	1090	1.5	1400	1.5	1400	1.5

53	KR-MUY03	quebec f/h 6" thick f/h le	20	1.370	1030	1	1280	1										
54	KR-MUY04	coffee table	22	1.507	1600	1.25												
55	KR-NOVAD	nova bed 4'6"	9	0.616														
56	KR-NOVAD	4'6" nova headboard	1	0.068														
57	KR-NOVA	nova bed 5'	10	0.685	KR-NOVA	0.685	KR-NOVA	0.411	KR-PAO2	0.959	KR-PA05	0.411	KR-PA12	0.616	KR-PA21	0.685	KR-PA22	0.890
58	KR-NOVAS	3' nova bed	6	0.411	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
59	KR-PAO2	panel 2 drawer bedside	14	0.959	1560	1.5	960	1.5	535	1	980	1	930	1	780	1	1290	1
60	KR-PA05	panel 2 drawer sidetable	6	0.411					570	1			1020	1	1100	1.25	1100	1.25
61	KR-PA12	2/3 chest of drawers	9	0.616					460	1					780	1	1290	1
62	KR-PA21	1 door wardrobe	10	0.685											780	1	1290	1
63	KR-PA22	2 door wardrobe	13	0.890														
64	KR-PA23	3 door wardrobe	30	2.055	KR-PA23	2.055	KR-PA24	3.014	KR-PA30	0.411	KR-PA35	0.822	KR-PA40	0.685	KR-PA50	0.959	KR-PABC	1.575
65	KR-PA24	4 door wardrobe	44	3.014	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
66	KR-PA30	panel corner cupboard	6	0.411	1840	1	2350	1	1850	1.25	1770	1	660	1	670	1	1070	1
67	KR-PA35	gerts wardrobe	12	0.822	1100	1.25	1100	1.25			1050	1	1120	1	650	1	1180	1
68	KR-PA40	panel wellington chest	10	0.685	1690	1	1690	1			1050	1			580	1	1180	1
69	KR-PA50	panel open top bedside/	14	0.959	645	1	1155	1									1290	1
70	KR-PABC0	panel bookcase 1962x3	23	1.575														
71	KR-PABC0	panel bookcase 40X48X	17	1.164	KR-PABC	1.164	KR-PABC	2.192	KR-PABC	2.329	KR-PBS	0.616	KR-PTBS	0.205	KR-PTBT	0.205	KR-Q1190	0.411
72	KR-PABC0	panel bookcase narrow	32	2.192	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
73	KR-PABC0	panel bookcase 82X49X	34	2.329	1070	1	1070	1	2150	1	1600	1	1550	1.25	1860	1.25		
74	KR-PBS	pot board server	9	0.616	1180	1	940	1	1180	1			width 200		widh 200		1290	1.25
75	KR-PTBS	butterfly table 5x 37.5	3	0.205	1180	1	900	1	1235	1								
76	KR-PTBT	butterfly table 6'	3	0.205	1290	1	1050	1										
77	KR-Q1190T	48" round table top	6	0.411														
78	KR-Q1406	small bookcase	16	1.096	KR-Q1406	1.096	KR-QHTO	4.178	KR-QHTO	1.712	KR-QDGB	0.274	KR-QGR3	0.616	KR-QGT3	0.342	KR-RBED	0.479
79	KR-QHTOP	f/h top thick 5'x35"	61	4.178	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
80	KR-QHTOP	f/h top 6'x35"	25	1.712	1070	1	1600	2	1900	2	2290	1.5	1300	1.25	1300	1	1360	1.5
81	KR-QDGB4	quebec gothic 4 door ba	4	0.274	940	1					920	1	1630	1	1630	1	1360	1.5
82	KR-QGR3	open gothic rack	9	0.616	900	1					2130	1	1700	1	1630	1	1.36	1.25
83	KR-QGT3	glazed rack 3 door	5	0.342	1020	1							1110	1				
84	KR-RBED5	ribbon and bow bed 4'6"	7	0.479														
85	KR-RBED6	ribbon and bow bed 5'	8	0.548	KR-RBED	0.548	KR-RBHB	0.137	KR-RT117	1.027	KR-RT118	1.027	KR-RT119	1.027	KR-RU	0.685	KR-T102	0.068
86	KR-RBHB6	ribbon and bow headbo	2	0.137	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
87	KR-RT117	round 35" ped. table	15	1.027	1510	1.5	1510	1	965	1.5	1140	1.5	1290	1.5	1850	1.25	1440	1
88	KR-RT118	round 42" ped table	15	1.027	1510	1.5												
89	KR-RT119	round 48" ped table	15	1.027	1510	1.25												
90	KR-RU	glazed corner unit rutland	10	0.685														
91	KR-T102	f/h 4'6"x 3"	1	0.068														
92	KR-T103	f/h 4'6"x 2'6"	26	1.781	KR-T103	1.781	KR-T04	1.986	KR-T101	0.068								
93	KR-T04	card table	29	1.986	length	thickness	length	thickness	length	thickness								
94	KR-T101	blue f/h 6'x 35"	1	0.068	1290	1	730	1	1900	2								
95	KR-TFHJ4	f/h table 5'x35"	0	0.000														
96	KR-TFHK4	f/h table 6'x35"	0	0.000														
97	KR-TFHL4	f/h table 6'x40"	0	0.000														
98	KR-TFHN4	f/h table 7'x40"	0	0.000														
99	KR-TT101	tongue table4'x30"	3	0.205	KR-TT101	0.205	KR-TT102	0.205	KR-TT110	0.068	KR-TT111	0.411	KR-TT139	0.068	KR-TT165	0.068	LANE 04	0.685
100	KR-TT102	tongue table4.5'x30" thin	3	0.205	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness
101	KR-TT110	tongue table5'x37"	1	0.068	1290	1	1440	1	1600	1.5	1900	1.5	1900	2	2600	2	1790	1.5
102	KR-TT111	tongue table6'x37" 1.5	6	0.411	950	1	1100	1									920	1
103	KR-TT139	tongue table6'x37" 1.5 e	1	0.068	580	1	610	1									1630	1
104	KR-TT165	8'x41" refectory table	1	0.068														
105	LANE 04	gothic dresser	10	0.685														
106	LANE27	cricket table waxed	12	0.822	LANE27	3.562	LANE39	1.507	LANE46	0.068	MACY10	4.041	MACY11	0.411	SOFA03	0.068	SOFA04	0.137
107	LANE39	astral glazed bookcase	22	1.507	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness	length	thickness

108	LANE46	console table	1	0.068	780	1.5	1240	1	1520	1.25	1340	1.25	730	1.25	1900	2	2200	2
109	MACY10	coffee table	59	4.041	570	1	1240	1										
110	MACY11	end table	6	0.411														
111	SOFA03	cross board table 6x44	1	0.068														
112	SOFA04	cross board table 7x44	2	0.137														
113	SOFA05	salernes bed	3	0.205	SOFA05	0.205												
		total number of products	###		length	thickness												
					1575	1.5												
					1575	1.5												
					1860	1.5												
					thickness	prob	thickness	prob	thickness	prob	thickness	prob	thickness	prob	thickness	prob	thickness	prob
					1	15.123	1	15.605	1	5.068	1	5.765	1	5.246	1	5.753	1	7.804
					1.25	2.877	1.25	4.178	1.25	2.671	1.25	5.205	1.25	2.055	1.25	2.260	1.25	2.260
					1.5	6.301	1.5	0.753	1.5	4.433	1.5	8.633	1.5	4.795	1.5	2.055	1.5	2.123
					2	0	2	4.178	2	2.123	2	1.370	2	0.068	2	0.137	2	0.753
													1x200	0.205	1x200	0.205		
					no of prod	16	no of prod	16	no of prod	16	no of prod	15	no of prods	14	no of prod	13	no of prod	15
					prod grou	20	prod grou	18	prod grou	18	prod grou	18	prod groups	17	prod grou	15	prod grou	19
																	total prods	105
																	prod grou	125
																	Ave number of comp grou	

	Data for Dimter							
TOTALS	PROB %	prob	p(1-p)	dur setup	dur(p(1-p)	(dur-mstc)	prevXp(1-p)	
				in min				
1	60.365	0.603651	0.239256	4	0.957026	3.357013	0.803187	
1.25	21.507	0.215068	0.168814	4	0.675256	4.468932	0.754418	
1.5	29.094	0.290939	0.206294	4	0.825175	3.857556	0.795789	
2	8.630	0.086301	0.078853	4	0.315414	6.119821	0.482569	
1x200	0.411	0.00411	0.004093	4	0.016371	7.688809	0.031468	
			0.30269	0	0	7.779865	2.354886	
		sum		mean	2.789241		5.222317	
				sd			2.285239	
					dur(p(1-p)	(dur-mstc)	prevXp(1-p)	
	Data for Resaw							
		0.603651	0.239256	3	0.717769	1.88832	0.451793	
s per pro	1.190476	0.215068	0.168814	3	0.506442	2.513774	0.42436	
		0.290939	0.206294	3	0.618881	2.169875	0.447632	
		0.086301	0.078853	3	0.23656	3.442399	0.271445	
		0.00411	0.004093	3	0.012278	4.324955	0.017701	
			0.30269	0	0	4.376174	1.324623	
				mean	2.091931		2.937553	
						sd	1.713929	

	CALCULATIONS FOR PLANER										
	Code	Desc.	No.	occur(p)	steup dur						
						same as	sum prob	p(1-p)	dur.p(1-p)	(x-x)^2	sd calc
1	C-PAFF 03	small bookcase front fra	17	0.012	40		0.077	0.070783	2.83132375	220.2638	15.59095
2	C-PAFF04	wide bookcase front fra	29	0.020		C-PAFF 03		0	0	0	0
3	C-Q1070T	Quebec farmhouse top	18	0.012	2		0.012	0.012169	0.02433708	536.326	6.526304
4	C-Q1080T	Quebec farmhouse top	16	0.011	2		0.011	0.010831	0.02166294	536.326	5.809199
7	ENIGMA 0	lamp table 20"x20"	4	0.003	6		0.003	0.00273	0.01638213	367.0563	1.002194
9	K-AFHB	farm house base arhous	30	0.021	16		0.021	0.020112	0.32179585	83.88205	1.687056
10	KR-430007	Consde	30	0.021	16		0.021	0.020112	0.32179585	83.88205	1.687056
11	KR-430014	cricket table wax	40	0.027	18		0.036	0.034325	0.61785478	51.24719	1.759073
12	KR-430095	wash stand	20	0.014	12		0.014	0.013502	0.1620223	173.1518	2.337871
13	KR-430151	leather top writing table	1	0.001	30		0.001	0.000684	0.02051983	23.43805	0.016031
14	KR-430185	cabriole leg end table	11	0.008	4		0.008	0.007472	0.02988961	447.6912	3.345329
15	KR-430214	triangle	12	0.008	6		0.008	0.008146	0.04887654	367.0563	2.990074
16	KR-430286	astragal bookcase	21	0.014	62		0.014	0.014167	0.878361	1357.28	19.22874
17	KR-AL19	19 drawer chest	20	0.014	46		0.014	0.013502	0.62108548	434.3592	5.864656
18	KR-BALL01	gothic dresser with locks	1	0.001		kr-3ddr		0	0	0	0
19	KR-OBOX0	blanket box 24"	13	0.009	26		0.009	0.008819	0.22928985	0.707762	0.006242
20	KR-OBOX0	ottoman 36"	11	0.008	26		0.014	0.014167	0.36834494	0.707762	0.010027
21	KR-OBOX0	ottoman 54"	10	0.007		KR-OBOX03		0	0	0	0
22	KR-CD01	computer cupboard	17	0.012	48		0.012	0.0115	0.55202268	521.7243	6.000076
23	KR-COBC0	corbel cupboard	13	0.009	44		0.009	0.008819	0.38802898	354.994	3.130636
24	KR-CTBA3	barley coffee 36"x24"	27	0.018	0	as quebec		0	0	0	0
25	KR-CTB3	barley coffee 42"x30"	29	0.020	0	as quebec		0	0	0	0
26	KR-CTBF	barley coffee 4'x3'	11	0.008	0	as quebec		0	0	0	0
27	KR-CTUSA	quebec coffee table 36"	17	0.012	24		0.030	0.029209	0.70102473	1.342619	0.039217
28	KR-CTUSA	quebec coffee table 42"	36	0.025	24		0.049	0.046853	1.12446399	1.342619	0.062905
29	KR-CTUSF	quebec coffee table 48"	19	0.013	24		0.021	0.020112	0.48269378	1.342619	0.027003
30	KR-BED1	daybed 4'6"	4	0.003		KR-BEDB1		0	0	0	0
31	KR-BEDB1	daybed 4'6" with back	12	0.008	14		0.011	0.010831	0.15164058	124.5169	1.348701
32	KR-FH101	4'x30" f/h table	20	0.014	6		0.129	0.112121	0.67272423	367.0563	41.15461
33	KR-FH106	4'6"x35" f/h table	20	0.014		KR-FH101		0	0	0	0
34	KR-FH107	5'x35" f/h table	21	0.014		KR-FH101		0	0	0	0
35	KR-FH108	6'x35" f/h table	13	0.009		KR-FH101		0	0	0	0
36	KR-FILE2P	2 drawer filing cabinet	24	0.016	44		0.016	0.016157	0.71091922	354.994	5.735729
37	KR-G2DDR	gothic 2 door dresser	5	0.003	30		0.003	0.003411	0.10231804	23.43805	0.079938
38	KR-G3DDR	gothic 3 door dresser	5	0.003	34		0.004	0.00409	0.13905696	78.16833	0.319701
39	KR-GCC	glazed corner cupboard	2	0.001	34		0.001	0.001367	0.04647975	78.16833	0.10686
40	KR-GDB2	2-door gothic dresser ba	2	0.001	30		0.001	0.001367	0.04101154	23.43805	0.032041
41	KR-GGBC	gothic glazed book case	14	0.010	22		0.010	0.009491	0.20879439	9.977476	0.094693
42	KR-GGDR3	gothic glazed dresser	9	0.006	30		0.006	0.006122	0.1836665	23.43805	0.143493
43	KR-GGDR4	gothic 4 dresser glazed	4	0.003	48		0.003	0.00273	0.13105704	521.7243	1.424493
44	KR-GRBC	gothic open bookcase	10	0.007	40		0.007	0.006798	0.27191112	220.2638	1.497304
45	KR-JENKIN	gothic glazed see spec	1	0.001	34		0.001	0.000684	0.0232558	78.16833	0.053467
46	KR -LP01L	louis phillipe pot cupboar	15	0.010	38		0.021	0.020112	0.76426514	164.8986	3.316481
47	KR -LP01R	louis phillipe pot cupboar	15	0.010	0	kr-lp10l		0	0	0	0
48	KR-LP10	louis phillipe double cod	13	0.009	44		0.009	0.008819	0.38802898	354.994	3.130636
49	KR-LP15	3+1 drawer chest	7	0.005	64		0.005	0.004768	0.30517011	1508.645	7.193648
50	KR-LP22	louis phillipe 2 door war	4	0.003	20		0.003	0.00273	0.0546071	26.61233	0.072661
51	KR-LP40	louis phillpie langene c/b	5	0.003	66		0.003	0.003411	0.22509968	1668.011	5.688919
52	KR-MUY02	quebec f/h 5" thick f/h le	20	0.014	6		0.014	0.013502	0.08101115	367.0563	4.955943
53	KR-MUY03	quebec f/h 6" thick f/h le	20	0.014	6		0.014	0.013502	0.08101115	367.0563	4.955943
54	KR-MUY04	coffee table	22	0.015	6		0.015	0.014831	0.08898858	367.0563	5.443971
55	KR-NOVAD	nova bed 4'6"	9	0.006	18		0.006	0.006122	0.1101999	51.24719	0.313746
56	KR-NOVAD	4'6" nova headboard	1	0.001	16		0.012	0.0115	0.18400756	83.88205	0.964683
57	KR-NOVA	nova bed 5'	10	0.007		KR-NOVAD		0	0	0	0
58	KR-NOVAS	3' nova bed	6	0.004		KR-NOVAD		0	0	0	0
59	KR-PAO2	panel 2 drawer bedside	14	0.010	42		0.010	0.009491	0.39860746	283.6289	2.691824
60	KR-PA05	panel 2 drawer sidetable	6	0.004	42		0.004	0.00409	0.17177624	283.6289	1.160017
61	KR-PA12	2/3 chest of drawers	9	0.006	52		0.006	0.006122	0.31835527	720.4546	4.410779
62	KR-PA21	1 door wardrobe	10	0.007	40		0.007	0.006798	0.27191112	220.2638	1.497304
63	KR-PA22	2 door wardrobe	13	0.009	52		0.009	0.008819	0.4585797	720.4546	6.353574
64	KR-PA23	3 door wardrobe	30	0.021	56		0.051	0.048085	2.6927484	951.1849	45.73753
65	KR-PA24	4 door wardrobe	44	0.030		KR-PA23		0	0	0	0
66	KR-PA30	panel corner cupboard	6	0.004	48		0.004	0.00409	0.19631571	521.7243	2.133806
67	KR-PA35	gents wardrobe	12	0.008	44		0.008	0.008146	0.35842796	354.994	2.891813
68	KR-PA40	panel wellington chest	10	0.007	52		0.007	0.006798	0.35348446	720.4546	4.897491
69	KR-PA50	panel open top bedside/	14	0.010	22		0.010	0.009491	0.20879439	9.977476	0.094693
70	KR-PABC0	panel bookcase 1962x3	23	0.016	40		0.016	0.015495	0.61979245	220.2638	3.412945
71	KR-PABC0	panel bookcase 40X48X	17	0.012	40		0.012	0.0115	0.4600189	220.2638	2.533137
72	KR-PABC0	panel bookcase narrow	32	0.022		C-PAFF 03		0	0	0	0
73	KR-PABC0	panel bookcase 82X49X	34	0.023		C-PAFF 03		0	0	0	0
74	KR-PBS	pot board server	9	0.006	48		0.006	0.006122	0.2938664	521.7243	3.194109
75	KR-PTBS	butterfly table 5x 37.5	3	0.002	20		0.004	0.00409	0.08179821	26.61233	0.108842
76	KR-PTBT	butterfly table 6'	3	0.002		KR-PTBS		0	0	0	0
77	KR-Q1190T	48" round table top	6	0.004	24		0.004	0.00409	0.09815785	1.342619	0.005491
78	KR-Q1406	small bookcase	16	0.011	66		0.011	0.010831	0.71487701	1668.011	18.06701
79	KR-QHTOP	f/h top thick 5'x35"	61	0.042		KR-FH101		0	0	0	0
80	KR-QHTOP	f/h top 6'x35"	25	0.017		KR-FH101		0	0	0	0
81	KR-QDGB4	quebec gothic 4 door ba	4	0.003	34		0.003	0.00273	0.09283207	78.16833	0.213427
82	KR-QGR3	open gothic rack	9	0.006	26		0.006	0.006122	0.15917763	0.707762	0.004333
83	KR-QGT3	glazed rack 3 door	5	0.003	26		0.003	0.003411	0.08867563	0.707762	0.002414
84	KR-RBED5	ribbon and bow bed 4'6"	7	0.005	10		0.010	0.010162	0.1016153	229.7866	2.334984

85	KR-RBED6	ribbon and bow bed 5'	8	0.005		KR-RBED54		0	0	0	0
86	KR-RBHB6	ribbon and bow headbo	2	0.001	6		0.001	0.001367	0.00820231	367.0563	0.501785
87	KR-RT117	round 35" ped. table	15	0.010	20		0.010	0.010162	0.20323061	26.61233	0.270422
88	KR-RT118	round 42" ped table	15	0.010	20		0.010	0.010162	0.20323061	26.61233	0.270422
89	KR-RT119	round 48" ped table	15	0.010	20		0.010	0.010162	0.20323061	26.61233	0.270422
90	KR-RU	glazed corner unit rutland	10	0.007	34		0.007	0.006798	0.23112445	78.16833	0.531371
91	KR-T102	f/h 4'6"x 3"	1	0.001		KR-FH101		0	0	0	0
92	KR-T103	f/h 4'6"x 2'6"	26	0.018		KR-FH101		0	0	0	0
93	KR-T04	card table	29	0.020				0	0	632.9609	0
94	KR-T101	blue f/h 6'x 35"	1	0.001		KR-FH101		0	0	0	0
99	KR-TT101	tongue table4'x30"	3	0.002	6		0.002	0.002049	0.01229503	367.0563	0.752161
100	KR-TT102	tongue table4.5'x30" thin	3	0.002	6		0.002	0.002049	0.01229503	367.0563	0.752161
101	KR-TT110	tongue table5'x37"	1	0.001	6		0.001	0.000684	0.00410397	367.0563	0.251064
102	KR-TT111	tongue table6'x37" 1.5 -	6	0.004	6		0.004	0.00409	0.02453946	367.0563	1.501228
103	KR-TT139	tongue table6'x37" 1.5 e	1	0.001	6		0.001	0.000684	0.00410397	367.0563	0.251064
104	KR-TT165	8'x41" refectory table	1	0.001	8		0.001	0.000684	0.00547195	294.4215	0.201383
105	LANE 04	gothic dresser	10	0.007	36		0.007	0.006798	0.24472001	117.5335	0.798966
106	LANE27	cricket table waxed	12	0.008		KR-430014		0	0	0	0
107	LANE39	astral glazed bookcase	22	0.015	28		0.015	0.014831	0.41528006	8.072904	0.119733
108	LANE46	console table	1	0.001	14		0.001	0.000684	0.00957592	124.5169	0.085169
109	MACY10	coffee table	59	0.040	14		0.040	0.038752	0.54253484	124.5169	4.82534
110	MACY11	end table	6	0.004	14		0.004	0.00409	0.05725875	124.5169	0.509263
111	SOFA03	cross board table 6x44	1	0.001	26		0.001	0.000684	0.01778385	0.707762	0.000484
112	SOFA04	cross board table 7x44	2	0.001	26		0.001	0.001367	0.03554334	0.707762	0.000968
113	SOFA05	salernes bed	3	0.002	28		0.002	0.002049	0.05737681	8.072904	0.016543
		total number of products	1461		0		zeros	0.052889		632.9609	33.47676
								mean	25.15871	sd	17.67146
	32 to go										

CALCULATIONS FOR SANDER

	Code	Desc	No.	occur(p)	steup dur	same as	sum prob	p(1-p)	dur.p(1-p)	(x-x)^2	sd calc
1	C-PAFF 03	small bookcase front fra	17	0.012	12		0.012	0.0115	0.13800567	0.001448	1.67E-05
2	C-PAFF04	wide bookcase front fra	29	0.020	12		0.020	0.019455	0.23346503	0.001448	2.82E-05
3	C-Q1070T	Quebec farmhouse top	18	0.012	12		0.012	0.012169	0.14602246	0.001448	1.76E-05
4	C-Q1080T	Quebec farmhouse top	16	0.011	12		0.011	0.010831	0.12997764	0.001448	1.57E-05
7	ENIGMA 0	lamp table 20"x20"	4	0.003	12		0.003	0.00273	0.03276426	0.001448	3.95E-06
9	K-AFHB	farm house base arhous	30	0.021	12		0.021	0.020112	0.24134689	0.001448	2.91E-05
10	KR-430007	Console	30	0.021	12		0.021	0.020112	0.24134689	0.001448	2.91E-05
11	KR-430014	cricket table wax	40	0.027	12		0.036	0.034325	0.41190319	0.001448	4.97E-05
12	KR-430095	wash stand	20	0.014	12		0.014	0.013502	0.1620223	0.001448	1.96E-05
13	KR-430151	leather top writing table	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
14	KR-430185	cabriole leg end table	11	0.008	12		0.008	0.007472	0.08966883	0.001448	1.08E-05
15	KR-430214	triangle	12	0.008	12		0.008	0.008146	0.09775308	0.001448	1.18E-05
16	KR-430286	astragal bookcase	21	0.014	12		0.014	0.014167	0.17000535	0.001448	2.05E-05
17	KR-AL19	19 drawer chest	20	0.014	12		0.014	0.013502	0.1620223	0.001448	1.96E-05
18	KR-BALL01	gothic dresser with locks	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
19	KR-OBOX0	blanket box 24"	13	0.009	12		0.009	0.008819	0.10582608	0.001448	1.28E-05
20	KR-OBOX0	ottoman 36"	11	0.008	12		0.008	0.007472	0.08966883	0.001448	1.08E-05
21	KR-OBOX0	ottoman 54"	10	0.007	12		0.007	0.006798	0.08157334	0.001448	9.84E-06
22	KR-CD01	computer cupboard	17	0.012	12		0.012	0.0115	0.13800567	0.001448	1.67E-05
23	KR-COBC0	corbel cupboard	13	0.009	12		0.009	0.008819	0.10582608	0.001448	1.28E-05
24	KR-CTBA3	barley coffee 36"x24"	27	0.018	12		0.018	0.018139	0.21766757	0.001448	2.63E-05
25	KR-CTB3	barley coffee 42"x30"	29	0.020	12		0.020	0.019455	0.23346503	0.001448	2.82E-05
26	KR-CTBF	barley coffee 4'x3'	11	0.008	12		0.008	0.007472	0.08966883	0.001448	1.08E-05
27	KR-CTUSA	quebec coffee table 36"	17	0.012	12		0.012	0.0115	0.13800567	0.001448	1.67E-05
28	KR-CTUSA	quebec coffee table 42"	36	0.025	12		0.025	0.024033	0.28840194	0.001448	3.48E-05
29	KR-CTUSF	quebec coffee table 48"	19	0.013	12		0.013	0.012836	0.154028	0.001448	1.86E-05
30	KR-BED1	daybed 4'6"	4	0.003	12		0.003	0.00273	0.03276426	0.001448	3.95E-06
31	KR-BEDB1	daybed 4'6" with back	12	0.008	12		0.008	0.008146	0.09775308	0.001448	1.18E-05
32	KR-FH101	4'x30" f/h table	20	0.014	12		0.014	0.013502	0.1620223	0.001448	1.96E-05
33	KR-FH106	4'6"x35" f/h table	20	0.014	12		0.014	0.013502	0.1620223	0.001448	1.96E-05
34	KR-FH107	5'x35" f/h table	21	0.014	12		0.014	0.014167	0.17000535	0.001448	2.05E-05
35	KR-FH108	6'x35" f/h table	13	0.009	12		0.009	0.008819	0.10582608	0.001448	1.28E-05
36	KR-FILE2P	2 drawer filing cabinet	24	0.016	12		0.016	0.016157	0.19388706	0.001448	2.34E-05
37	KR-G2DDR	gothic 2 door dresser	5	0.003	12		0.003	0.003411	0.04092722	0.001448	4.94E-06
38	KR-G3DDR	gothic 3 door dresser	5	0.003	12		0.003	0.003411	0.04092722	0.001448	4.94E-06
39	KR-GCC	glazed corner cupboard	2	0.001	12		0.001	0.001367	0.01640462	0.001448	1.98E-06
40	KR-GDB2	2-door gothic dresser ba	2	0.001	12		0.001	0.001367	0.01640462	0.001448	1.98E-06
41	KR-GGBC	gothic glazed book case	14	0.010	12		0.010	0.009491	0.11388785	0.001448	1.37E-05
42	KR-GGDR3	gothic glazed dresser	9	0.006	12		0.006	0.006122	0.0734666	0.001448	8.87E-06
43	KR-GGDR4	gothic 4 dresser glazed	4	0.003	12		0.003	0.00273	0.03276426	0.001448	3.95E-06
44	KR-GRBC	gothic open bookcase	10	0.007	12		0.007	0.006798	0.08157334	0.001448	9.84E-06
45	KR-JENKIN	gothic glazed see spec	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
46	KR -LP01L	louis phillipe pot cupboar	15	0.010	12		0.010	0.010162	0.12193836	0.001448	1.47E-05
47	KR -LP01R	louis phillipe pot cupboar	15	0.010	12		0.010	0.010162	0.12193836	0.001448	1.47E-05
48	KR-LP10	louis phillipe double cod	13	0.009	12		0.009	0.008819	0.10582608	0.001448	1.28E-05
49	KR-LP15	3+1 drawer chest	7	0.005	12		0.005	0.004768	0.05721939	0.001448	6.91E-06
50	KR-LP22	louis phillipe 2 door war	4	0.003	12		0.003	0.00273	0.03276426	0.001448	3.95E-06
51	KR-LP40	louis phillipe langene c/b	5	0.003	12		0.003	0.003411	0.04092722	0.001448	4.94E-06
52	KR-MUY02	quebec f/h 5" thick f/h le	20	0.014	12		0.014	0.013502	0.1620223	0.001448	1.96E-05
53	KR-MUY03	quebec f/h 6" thick f/h le	20	0.014	12		0.014	0.013502	0.1620223	0.001448	1.96E-05
54	KR-MUY04	coffee table	22	0.015	12		0.015	0.014831	0.17797717	0.001448	2.15E-05
55	KR-NOVAD	nova bed 4'6"	9	0.006	12		0.018	0.017479	0.20975198	0.001448	2.53E-05
56	KR-NOVAD	4'6" nova headboard	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
57	KR-NOVA	nova bed 5'	10	0.007	12		0.007	0.006798	0.08157334	0.001448	9.84E-06
58	KR-NOVAS	3' nova bed	6	0.004	12		0.004	0.00409	0.04907893	0.001448	5.92E-06
59	KR-PAO2	panel 2 drawer bedside	14	0.010	12		0.010	0.009491	0.11388785	0.001448	1.37E-05
60	KR-PA05	panel 2 drawer sidetable	6	0.004	12		0.004	0.00409	0.04907893	0.001448	5.92E-06
61	KR-PA12	2/3 chest of drawers	9	0.006	12		0.006	0.006122	0.0734666	0.001448	8.87E-06
62	KR-PA21	1 door wardrobe	10	0.007	12		0.007	0.006798	0.08157334	0.001448	9.84E-06
63	KR-PA22	2 door wardrobe	13	0.009	12		0.009	0.008819	0.10582608	0.001448	1.28E-05
64	KR-PA23	3 door wardrobe	30	0.021	12		0.021	0.020112	0.24134689	0.001448	2.91E-05
65	KR-PA24	4 door wardrobe	44	0.030	12		0.030	0.029209	0.35051236	0.001448	4.23E-05
66	KR-PA30	panel corner cupboard	6	0.004	12		0.004	0.00409	0.04907893	0.001448	5.92E-06
67	KR-PA35	gents wardrobe	12	0.008	12		0.008	0.008146	0.09775308	0.001448	1.18E-05
68	KR-PA40	panel wellington chest	10	0.007	12		0.007	0.006798	0.08157334	0.001448	9.84E-06
69	KR-PA50	panel open top bedside/	14	0.010	12		0.010	0.009491	0.11388785	0.001448	1.37E-05
70	KR-PABC0	panel bookcase 1962x3	23	0.016	12		0.016	0.015495	0.18593773	0.001448	2.24E-05
71	KR-PABC0	panel bookcase 40X48X	17	0.012	12		0.012	0.0115	0.13800567	0.001448	1.67E-05
72	KR-PABC0	panel bookcase narrow	32	0.022	12		0.022	0.021423	0.25707688	0.001448	3.1E-05
73	KR-PABC0	panel bookcase 82X49X	34	0.023	12		0.023	0.02273	0.2727619	0.001448	3.29E-05
74	KR-PBS	pot board server	9	0.006	12		0.006	0.006122	0.0734666	0.001448	8.87E-06
75	KR-PTBS	butterfly table 5x 37.5	3	0.002	12		0.002	0.002049	0.02459006	0.001448	2.97E-06
76	KR-PTBT	butterfly table 6'	3	0.002	12		0.004	0.00409	0.04907893	0.001448	5.92E-06
77	KR-Q1190T	48" round table top	6	0.004	12		0.004	0.00409	0.04907893	0.001448	5.92E-06
78	KR-Q1406	small bookcase	16	0.011	12		0.011	0.010831	0.12997764	0.001448	1.57E-05
79	KR-QHTOP	f/h top thick 5'x35"	61	0.042	12		0.042	0.040009	0.48010772	0.001448	5.79E-05
80	KR-QHTOP	f/h top 6'x35"	25	0.017	12		0.017	0.016819	0.20182514	0.001448	2.44E-05
81	KR-QDGB4	quebec gothic 4 door ba	4	0.003	12		0.003	0.00273	0.03276426	0.001448	3.95E-06
82	KR-QGR3	open gothic rack	9	0.006	12		0.006	0.006122	0.0734666	0.001448	8.87E-06
83	KR-QGT3	glazed rack 3 door	5	0.003	12		0.003	0.003411	0.04092722	0.001448	4.94E-06
84	KR-RBED5	ribbon and bow bed 4'6"	7	0.005	12		0.005	0.004768	0.05721939	0.001448	6.91E-06

85	KR-RBED6	ribbon and bow bed 5'	8	0.005	12		0.005	0.005446	0.06534862	0.001448	7.89E-06
86	KR-RBHB6	ribbon and bow headbo	2	0.001	12		0.001	0.001367	0.01640462	0.001448	1.98E-06
87	KR-RT117	round 35" ped. table	15	0.010	12		0.010	0.010162	0.12193836	0.001448	1.47E-05
88	KR-RT118	round 42" ped table	15	0.010	12		0.010	0.010162	0.12193836	0.001448	1.47E-05
89	KR-RT119	round 48" ped table	15	0.010	12		0.010	0.010162	0.12193836	0.001448	1.47E-05
90	KR-RU	glazed corner unit rutland	10	0.007	12		0.007	0.006798	0.08157334	0.001448	9.84E-06
91	KR-T102	f/h 4'6"x 3"	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
92	KR-T103	f/h 4'6"x 2'6"	26	0.018	12		0.018	0.017479	0.20975198	0.001448	2.53E-05
93	KR-T04	card table	29	0.020	12		0.020	0.019455	0.23346503	0.001448	2.82E-05
94	KR-T101	blue f/h 6'x 35"	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
99	KR-TT101	tongue table4'x30"	3	0.002	12		0.002	0.002049	0.02459006	0.001448	2.97E-06
100	KR-TT102	tongue table4.5'x30" thin	3	0.002	12		0.002	0.002049	0.02459006	0.001448	2.97E-06
101	KR-TT110	tongue table5'x37"	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
102	KR-TT111	tongue table6'x37" 1.5	6	0.004	12		0.004	0.00409	0.04907893	0.001448	5.92E-06
103	KR-TT139	tongue table6'x37" 1.5 e	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
104	KR-TT165	8'x41" refectory table	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
105	LANE 04	gothic dresser	10	0.007	12		0.007	0.006798	0.08157334	0.001448	9.84E-06
106	LANE27	cricket table waxed	12	0.008	12	as prev		0	0		0
107	LANE39	astral glazed bookcase	22	0.015	12		0.015	0.014831	0.17797717	0.001448	2.15E-05
108	LANE46	console table	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
109	MACY10	coffee table	59	0.040	12		0.040	0.038752	0.46502986	0.001448	5.61E-05
110	MACY11	end table	6	0.004	12		0.004	0.00409	0.04907893	0.001448	5.92E-06
111	SOFA03	cross board table 6x44	1	0.001	12		0.001	0.000684	0.00820793	0.001448	9.91E-07
112	SOFA04	cross board table 7x44	2	0.001	12		0.001	0.001367	0.01640462	0.001448	1.98E-06
113	SOFA05	salernes bed	3	0.002	12		0.002	0.002049	0.02459006	0.001448	2.97E-06
		total number of products	1461		0		zeros	0.003171		143.0881	0.453762
									11.96195		0.674689
											put in zeros

	CALCULATIONS FOR PRESS										
	Code	Desc.	No.	occur(p)	steup dur						
						same as	sum prob	p(1-p)	dur.p(1-p)	(x-x)^2	sd calc
1	C-PAFF 03	small bookcase front fra	17	0.012	2		0.012	0.011739	0.02347735	3.997289	0.046923
2	C-PAFF04	wide bookcase front fra	29	0.020	2		0.020	0.019855	0.03970971	3.997289	0.079366
3	C-Q1070T	Quebec farmhouse top	18	0.013	2		0.013	0.01242	0.02484079	3.997289	0.049648
4	C-Q1080T	Quebec farmhouse top	16	0.011	2		0.011	0.011056	0.02211196	3.997289	0.044194
7	ENIGMA 0	lamp table 20"x20"	4	0.003	2		0.003	0.002787	0.00557487	3.997289	0.011142
9	K-AFHB	farm house base arhous	0	0.000	0		0.000	0	0	0	0
10	KR-430007	Console	30	0.021	2		0.021	0.020525	0.04104971	3.997289	0.082044
11	KR-430014	cricket table wax	40	0.028	4		0.028	0.027171	0.10868456	4.59E-07	1.25E-08
12	KR-430095	wash stand	20	0.014	4		0.014	0.013781	0.05512362	4.59E-07	6.33E-09
13	KR-430151	leather top writing table	1	0.001	2		0.001	0.000698	0.00139665	3.997289	0.002791
14	KR-430185	cabriole leg end table	11	0.008	2		0.008	0.007628	0.01525569	3.997289	0.030491
15	KR-430214	triangle	12	0.008	2		0.008	0.008315	0.01663085	3.997289	0.033239
16	KR-430286	astragal bookcase	21	0.015	2		0.015	0.01446	0.02891939	3.997289	0.0578
17	KR-AL19	19 drawer chest	20	0.014	4		0.014	0.013781	0.05512362	4.59E-07	6.33E-09
18	KR-BALL01	gothic dresser with locks	1	0.001	10		0.001	0.000698	0.00698324	36.00813	0.025145
19	KR-OBOX0	blanket box 24"	13	0.009	6		0.009	0.009002	0.05401216	4.002712	0.036033
20	KR-OBOX0	ottoman 36"	11	0.008	6		0.015	0.01446	0.08675817	4.002712	0.057878
21	KR-OBOX0	ottoman 54"	10	0.007		as above		0	0	0	0
22	KR-CD01	computer cupboard	17	0.012	12		0.012	0.011739	0.14086409	64.01085	0.751402
23	KR-COBC0	corbel cupboard	13	0.009	6		0.009	0.009002	0.05401216	4.002712	0.036033
24	KR-CTBA3	barley coffee 36"x24"	27	0.019	2		0.019	0.018512	0.03702385	3.997289	0.073998
25	KR-CTB3	barley coffee 42"x30"	29	0.020	2		0.020	0.019855	0.03970971	3.997289	0.079366
26	KR-CTBF	barley coffee 4'x3'	11	0.008	2		0.008	0.007628	0.01525569	3.997289	0.030491
27	KR-CTUSA	quebec coffee table 36"	17	0.012	2		0.012	0.011739	0.02347735	3.997289	0.046923
28	KR-CTUSA	quebec coffee table 42"	36	0.025	2		0.025	0.024524	0.04904869	3.997289	0.098031
29	KR-CTUSF	quebec coffee table 48"	19	0.013	2		0.013	0.013101	0.02620228	3.997289	0.052369
30	KR-BED1	daybed 4'6"	4	0.003	2		0.003	0.002787	0.00557487	3.997289	0.011142
31	KR-BEDB1	daybed 4'6" with back	12	0.008	4		0.008	0.008315	0.03326169	4.59E-07	3.82E-09
32	KR-FH101	4'x30" f/h table	20	0.014	2		0.014	0.013781	0.02756181	3.997289	0.055086
33	KR-FH106	4'6"x35" f/h table	20	0.014	2		0.038	0.036312	0.07262371	3.997289	0.145149
34	KR-FH107	5'x35" f/h table	21	0.015		as above		0	0	0	0
35	KR-FH108	6'x35" f/h table	13	0.009		as above		0	0	0	0
36	KR-FILE2P	2 drawer filing cabinet	24	0.017	8		0.017	0.01649	0.13192165	16.00542	0.263933
37	KR-G2DDR	gothic 2 door dresser	5	0.003	10		0.003	0.003482	0.03481852	36.00813	0.125375
38	KR-G3DDR	gothic 3 door dresser	5	0.003	10		0.003	0.003482	0.03481852	36.00813	0.125375
39	KR-GCC	glazed corner cupboard	2	0.001	2		0.001	0.001396	0.00279134	3.997289	0.005579
40	KR-GDB2	2-door gothic dresser ba	2	0.001	6		0.001	0.001396	0.00837402	4.002712	0.005586
41	KR-GGBC	gothic glazed book case	14	0.010	4		0.010	0.009688	0.03875062	4.59E-07	4.45E-09
42	KR-GGDR3	gothic glazed dresser	9	0.006	10		0.006	0.00625	0.06249753	36.00813	0.225042
43	KR-GGDR4	gothic 4 dresser glazed	4	0.003	10		0.003	0.002787	0.02787435	36.00813	0.10037
44	KR-GRBC	gothic open bookcase	10	0.007	6		0.007	0.006939	0.04163572	4.002712	0.027776
45	KR-JENKIN	gothic glazed see spec	1	0.001	10		0.001	0.000698	0.00698324	36.00813	0.025145
46	KR -LP01L	louis philipe pot cupboar	15	0.010	8		0.021	0.020525	0.16419885	16.00542	0.328509
47	KR -LP01R	louis philipe pot cupboar	15	0.010	0	as above		0	0	0	0
48	KR-LP10	louis philipe double cod	13	0.009	4		0.014	0.013781	0.05512362	4.59E-07	6.33E-09
49	KR-LP15	3+1 drawer chest	7	0.005		as above		0	0	0	0
50	KR-LP22	louis phillipe 2 door war	4	0.003	6		0.003	0.002787	0.01672461	4.002712	0.011157
51	KR-LP40	louis philipie langene c/b	5	0.003	4		0.003	0.003482	0.01392741	4.59E-07	1.6E-09
52	KR-MUY02	quebec f/h 5" thick f/h le	20	0.014	2		0.028	0.027171	0.05434228	3.997289	0.108611
53	KR-MUY03	quebec f/h 6" thick f/h le	20	0.014		as above		0	0	0	0
54	KR-MUY04	coffee table	22	0.015	2		0.015	0.015138	0.03027502	3.997289	0.060509
55	KR-NOVAD	nova bed 4'6"	9	0.006	2		0.018	0.017839	0.03567799	3.997289	0.071308
56	KR-NOVAD	4'6" nova headboard	1	0.001		as above		0	0	0	0
57	KR-NOVA	nova bed 5'	10	0.007		as above		0	0	0	0
58	KR-NOVAS	3' nova bed	6	0.004		as above		0	0	0	0
59	KR-PAO2	panel 2 drawer bedside	14	0.010	6		0.010	0.009688	0.05812592	4.002712	0.038777
60	KR-PA05	panel 2 drawer sidetable	6	0.004	2		0.004	0.004175	0.00835058	3.997289	0.01669
61	KR-PA12	2/3 chest of drawers	9	0.006	4		0.006	0.00625	0.02499901	4.59E-07	2.87E-09
62	KR-PA21	1 door wardrobe	10	0.007	6		0.016	0.015814	0.09488607	4.002712	0.0633
63	KR-PA22	2 door wardrobe	13	0.009		as above		0	0	0	0
64	KR-PA23	3 door wardrobe	30	0.021	10		0.052	0.049038	0.49037949	36.00813	1.765765
65	KR-PA24	4 door wardrobe	44	0.031		as above		0	0	0	0
66	KR-PA30	panel corner cupboard	6	0.004	2		0.004	0.004175	0.00835058	3.997289	0.01669
67	KR-PA35	gents wardrobe	12	0.008	4		0.008	0.008315	0.03326169	4.59E-07	3.82E-09
68	KR-PA40	panel wellington chest	10	0.007	4		0.007	0.006939	0.02775715	4.59E-07	3.19E-09
69	KR-PA50	panel open top bedside/	14	0.010	6		0.010	0.009688	0.05812592	4.002712	0.038777
70	KR-PABC0	panel bookcase 1962x3	23	0.016	6		0.016	0.015814	0.09488607	4.002712	0.0633
71	KR-PABC0	panel bookcase 40X48X	17	0.012	6		0.012	0.011739	0.07043205	4.002712	0.046987
72	KR-PABC0	panel bookcase narrow	32	0.022	8		0.022	0.021862	0.17489541	16.00542	0.349909
73	KR-PABC0	panel bookcase 82X49X	34	0.024	6		0.024	0.023195	0.13917054	4.002712	0.092843
74	KR-PBS	pot board server	9	0.006	6		0.006	0.00625	0.03749852	4.002712	0.025016
75	KR-PTBS	butterfly table 5x 37.5	3	0.002	2		0.004	0.004175	0.00835058	3.997289	0.01669
76	KR-PTBT	butterfly table 6'	3	0.002		as above		0	0	0	0
77	KR-Q1190T	48" round table top	6	0.004	4		0.004	0.004175	0.01670117	4.59E-07	1.92E-09
78	KR-Q1406	small bookcase	16	0.011	6		0.011	0.011056	0.06633587	4.002712	0.044254
79	KR-QHTOP	f/h top thick 5'x35"	61	0.043	2		0.060	0.056486	0.11297217	3.997289	0.225791
80	KR-QHTOP	f/h top 6'x35"	25	0.017		as above		0	0	0	0
81	KR-QDGB4	quebec gothic 4 door ba	4	0.003	6		0.003	0.002787	0.01672461	4.002712	0.011157
82	KR-QGR3	open gothic rack	9	0.006	4		0.006	0.00625	0.02499901	4.59E-07	2.87E-09
83	KR-QGT3	glazed rack 3 door	5	0.003	4		0.003	0.003482	0.01392741	4.59E-07	1.6E-09
84	KR-RBED5	ribbon and bow bed 4'6"	7	0.005	2		0.012	0.011739	0.02347735	3.997289	0.046923

85	KR-RBED6	ribbon and bow bed 5'	8	0.006		as above		0	0	0	0
86	KR-RBHB6	ribbon and bow headbo	2	0.001		as above		0	0	0	0
87	KR-RT117	round 35" ped. table	15	0.010	2		0.010	0.010372	0.02074461	3.997289	0.041461
88	KR-RT118	round 42" ped table	15	0.010	2		0.010	0.010372	0.02074461	3.997289	0.041461
89	KR-RT119	round 48" ped table	15	0.010	2		0.010	0.010372	0.02074461	3.997289	0.041461
90	KR-RU	glazed corner unit rutland	10	0.007	2		0.007	0.006939	0.01387857	3.997289	0.027738
91	KR-T102	f/h 4'6"x 3"	1	0.001	2		0.001	0.000698	0.00139665	3.997289	0.002791
92	KR-T103	f/h 4'6"x 2'6"	26	0.018	2		0.018	0.017839	0.03567799	3.997289	0.071308
93	KR-T04	card table	29	0.020	2		0.020	0.019855	0.03970971	3.997289	0.079366
94	KR-T101	blue f/h 6'x 35"	1	0.001	2		0.001	0.000698	0.00139665	3.997289	0.002791
95	KR-TT101	tongue table4'x30"	3	0.002	2		0.002	0.002092	0.00418408	3.997289	0.008362
96	KR-TT102	tongue table4.5'x30" thin	3	0.002	2		0.003	0.002787	0.00557487	3.997289	0.011142
97	KR-TT110	tongue table5'x37"	1	0.001		as above		0	0	0	0
98	KR-TT111	tongue table6'x37" 1.5	6	0.004	2		0.005	0.004868	0.00973551	3.997289	0.019458
99	KR-TT139	tongue table6'x37" 1.5 e	1	0.001		as above		0	0	0	0
100	KR-TT165	8'x41" refectory table	1	0.001	2		0.001	0.000698	0.00139665	3.997289	0.002791
101	LANE 04	gothic dresser	10	0.007	6		0.015	0.015138	0.09082505	4.002712	0.060591
102	LANE27	cricket table waxed	12	0.008	4	as above		0	0	0	0
103	LANE39	astral glazed bookcase	22	0.015	4		0.015	0.015138	0.06055003	4.59E-07	6.95E-09
104	LANE46	console table	1	0.001	6		0.001	0.000698	0.00418994	4.002712	0.002795
105	MACY10	coffee table	59	0.041	4		0.041	0.03953	0.15812001	4.59E-07	1.82E-08
106	MACY11	end table	6	0.004	4		0.004	0.004175	0.01670117	4.59E-07	1.92E-09
107	SOFA03	cross board table 6x44	1	0.001	6		0.001	0.000698	0.00418994	4.002712	0.002795
108	SOFA04	cross board table 7x44	2	0.001	4		0.001	0.001396	0.00558268	4.59E-07	6.41E-10
109	SOFA05	salernes bed	3	0.002	4		0.002	0.002092	0.00836816	4.59E-07	9.61E-10
110		total number of products	1431		0		zeros	0.021448		15.99458	0.343057
111									3.999322		2.653902
112	32 to go										put in zeros
113											

CALCULATIONS FOR DIMSAW

	Code	Desc	No.	occur(p) %	dur	same as	sum prob	p(1-p)	dur.p(1-p)	(x-x)^2	sd calc
1	C-PAFF 03	small bookcase front fra	17	0.012	33		0.012	0.0115	0.37951559	142.9887	1.644437
2	C-PAFF04	wide bookcase front fra	29	0.020	39		0.020	0.019455	0.75876133	322.4821	6.274024
3	C-Q1070T	Quebec farmhouse top	18	0.000			0.000	0	0	0	0
4	C-Q1080T	Quebec farmhouse top	16	0.000			0.000	0	0	0	0
7	ENIGMA 0	lamp table 20"x20"	4	0.003	6		0.003	0.00273	0.01638213	226.2682	0.617792
9	K-AFHB	farm house base arhous	30	0.021	9		0.021	0.020112	0.18101017	145.0149	2.916575
10	KR-430007	Console	30	0.021	15		0.021	0.020112	0.30168361	36.50834	0.734265
11	KR-430014	cricket table wax	40	0.027	9		0.036	0.034325	0.30892739	145.0149	4.977675
12	KR-430095	wash stand	20	0.014	15		0.014	0.013502	0.20252787	36.50834	0.49293
13	KR-430151	leather top writing table	1	0.001	45		0.001	0.000684	0.03077974	573.9755	0.392596
14	KR-430185	cabriole leg end table	11	0.008	18		0.008	0.007472	0.13450324	9.255061	0.069158
15	KR-430214	triangle	12	0.008	6		0.008	0.008146	0.04887654	226.2682	1.843201
16	KR-430286	astragal bookcase	21	0.014	42		0.014	0.014167	0.59501874	439.2288	6.222604
17	KR-AL19	19 drawer chest	20	0.014	72		0.014	0.013502	0.97213379	2596.696	35.06022
18	KR-BALL01	gothic dresser with locks	1	0.001	66		0.001	0.000684	0.04514362	2021.203	1.382491
19	KR-OBOX0	blanket box 24"	13	0.009	13		0.009	0.008819	0.11464493	64.67719	0.570378
20	KR-OBOX0	ottoman 36"	11	0.008	13		0.008	0.007472	0.09714123	64.67719	0.483294
21	KR-OBOX0	ottoman 54"	10	0.007	13		0.007	0.006798	0.08837111	64.67719	0.439661
22	KR-CD01	computer cupboard	17	0.012	63		0.012	0.0115	0.72452977	1760.456	20.24607
23	KR-COBC0	corbel cupboard	13	0.009	24		0.009	0.008819	0.21165217	8.748503	0.077152
24	KR-CTBA3	barley coffee 36"x24"	27	0.018	12		0.018	0.018139	0.21766757	81.76162	1.483071
25	KR-CTB3	barley coffee 42"x30"	29	0.020	12		0.020	0.019455	0.23346503	81.76162	1.590707
26	KR-CTBF	barley coffee 4'x3'	11	0.008	12		0.008	0.007472	0.08966883	81.76162	0.610956
27	KR-CTUSA	quebec coffee table 36"	17	0.012	12		0.012	0.0115	0.13800567	81.76162	0.940297
28	KR-CTUSA	quebec coffee table 42"	36	0.025	12		0.025	0.024033	0.28840194	81.76162	1.965017
29	KR-CTUSF	quebec coffee table 48"	19	0.013	12		0.013	0.012836	0.154028	81.76162	1.049465
30	KR-BED1	daybed 4'6"	4	0.003	12		0.003	0.00273	0.03276426	81.76162	0.223238
31	KR-BEDB1	daybed 4'6" with back	12	0.008	12		0.008	0.008146	0.09775308	81.76162	0.666038
32	KR-FH101	4'x30" f/h table	20	0.014	6		0.014	0.013502	0.08101115	226.2682	3.055041
33	KR-FH106	4'6"x35" f/h table	20	0.014	6		0.014	0.013502	0.08101115	226.2682	3.055041
34	KR-FH107	5'x35" f/h table	21	0.014	6		0.014	0.014167	0.08500268	226.2682	3.205567
35	KR-FH108	6'x35" f/h table	13	0.009	6		0.009	0.008819	0.05291304	226.2682	1.995423
36	KR-FILE2P	2 drawer filing cabinet	24	0.016	24		0.016	0.016157	0.38777412	8.748503	0.141352
37	KR-G2DDR	gothic 2 door dresser	5	0.003	57		0.003	0.003411	0.19440427	1292.962	4.409779
38	KR-G3DDR	gothic 3 door dresser	5	0.003	57		0.003	0.003411	0.19440427	1292.962	4.409779
39	KR-GCC	glazed corner cupboard	2	0.001			0.001	0.001367	0	442.7747	0.605296
40	KR-GDB2	2-door gothic dresser ba	2	0.001	30		0.001	0.001367	0.04101154	80.24194	0.109695
41	KR-GGBC	gothic glazed book case	14	0.010	39		0.010	0.009491	0.3701355	322.4821	3.060566
42	KR-GGDR3	gothic glazed dresser	9	0.006	54		0.006	0.006122	0.3305997	1086.216	6.650048
43	KR-GGDR4	gothic 4 dresser glazed	4	0.003	54		0.003	0.00273	0.14743917	1086.216	2.965754
44	KR-GRBC	gothic open bookcase	10	0.007	36		0.007	0.006798	0.24472001	223.7354	1.520903
45	KR-JENKIN	gothic glazed see spec	1	0.001	57		0.001	0.000684	0.03898767	1292.962	0.884379
46	KR -LP01L	louis phillipe pot cupboar	15	0.010	33		0.010	0.010162	0.3353305	142.9887	1.452984
47	KR -LP01R	louis phillipe pot cupboar	15	0.010	33		0.010	0.010162	0.3353305	142.9887	1.452984
48	KR-LP10	louis phillipe double cod	13	0.009	57		0.009	0.008819	0.5026739	1292.962	11.40243
49	KR-LP15	3+1 drawer chest	7	0.005	54		0.005	0.004768	0.25748728	1086.216	5.179384
50	KR-LP22	louis phillipe 2 door war	4	0.003	33		0.003	0.00273	0.09010171	142.9887	0.39041
51	KR-LP40	louis philipe langene c/b	5	0.003	45		0.003	0.003411	0.15347706	573.9755	1.957602
52	KR-MUY02	quebec f/h 5" thick f/h le	20	0.014	9		0.014	0.013502	0.12151672	145.0149	1.957971
53	KR-MUY03	quebec f/h 6" thick f/h le	20	0.014	9		0.014	0.013502	0.12151672	145.0149	1.957971
54	KR-MUY04	coffee table	22	0.015	6		0.015	0.014831	0.08898858	226.2682	3.355881
55	KR-NOVAD	nova bed 4'6"	9	0.006	12		0.018	0.017479	0.20975198	81.76162	1.429138
56	KR-NOVAD	4'6" nova headboard	1	0.001	3		0.001	0.000684	0.00205198	325.5215	0.222655
57	KR-NOVA	nova bed 5'	10	0.007	12		0.007	0.006798	0.08157334	81.76162	0.555797
58	KR-NOVAS	3' nova bed	6	0.004	12		0.004	0.00409	0.04907893	81.76162	0.334398
59	KR-PAO2	panel 2 drawer bedside	14	0.010	30		0.010	0.009491	0.28471962	80.24194	0.761549
60	KR-PA05	panel 2 drawer sidetable	6	0.004	24		0.004	0.00409	0.09815785	8.748503	0.035781
61	KR-PA12	2/3 chest of drawers	9	0.006	36		0.006	0.006122	0.2203998	223.7354	1.369757
62	KR-PA21	1 door wardrobe	10	0.007	45		0.007	0.006798	0.30590001	573.9755	3.901758
63	KR-PA22	2 door wardrobe	13	0.009	51		0.009	0.008819	0.44976086	897.469	7.914636
64	KR-PA23	3 door wardrobe	30	0.021	51		0.021	0.020112	1.02572427	897.469	18.05011
65	KR-PA24	4 door wardrobe	44	0.030	51		0.030	0.029209	1.48967754	897.469	26.2145
66	KR-PA30	panel corner cupboard	6	0.004	27		0.004	0.00409	0.11042759	35.49522	0.145172
67	KR-PA35	gents wardrobe	12	0.008	51		0.008	0.008146	0.41545059	897.469	7.310863
68	KR-PA40	panel wellington chest	10	0.007	27		0.007	0.006798	0.18354001	35.49522	0.241289
69	KR-PA50	panel open top bedside/	14	0.010	15		0.010	0.009491	0.14235981	36.50834	0.346488
70	KR-PABC0	panel bookcase 1962x3	23	0.016	33		0.016	0.015495	0.51132877	142.9887	2.215582
71	KR-PABC0	panel bookcase 40X48X	17	0.012	33		0.012	0.0115	0.37951559	142.9887	1.644437
72	KR-PABC0	panel bookcase narrow	32	0.022	33		0.022	0.021423	0.70696142	142.9887	3.063257
73	KR-PABC0	panel bookcase 82X49X	34	0.023	39		0.023	0.02273	0.88647617	322.4821	7.330069
74	KR-PBS	pot board server	9	0.006	36		0.006	0.006122	0.2203998	223.7354	1.369757
75	KR-PTBS	butterfly table 5x 37.5	3	0.002	12		0.002	0.002049	0.02459006	81.76162	0.167544
76	KR-PTBT	butterfly table 6'	3	0.002	12		0.004	0.00409	0.04907893	81.76162	0.334398
77	KR-Q1190T	48" round table top	6	0.004	15		0.004	0.00409	0.06134866	36.50834	0.149316
78	KR-Q1406	small bookcase	16	0.011	18		0.011	0.010831	0.19496646	9.255061	0.100246
79	KR-QHTOP	f/h top thick 5'x35"	61	0.000			0.000	0	0	0	0
80	KR-QHTOP	f/h top 6'x35"	25	0.000			0.000	0	0	0	0
81	KR-QDGB4	quebec gothic 4 door ba	4	0.003	30		0.003	0.00273	0.08191065	80.24194	0.219089
82	KR-QGR3	open gothic rack	9	0.006	27		0.006	0.006122	0.16529985	35.49522	0.217309
83	KR-QGT3	glazed rack 3 door	5	0.003	24		0.003	0.003411	0.08185443	8.748503	0.029838
84	KR-RBED5	ribbon and bow bed 4'6"	7	0.005	9		0.005	0.004768	0.04291455	145.0149	0.691472

85	KR-RBED6	ribbon and bow bed 5'	8	0.005	9		0.005	0.005446	0.04901146	145.0149	0.78971
86	KR-RBHB6	ribbon and bow headbo	2	0.001	6		0.001	0.001367	0.00820231	226.2682	0.30932
87	KR-RT117	round 35" ped. table	15	0.000			0.000	0	0	0	0
88	KR-RT118	round 42" ped table	15	0.000			0.000	0	0	0	0
89	KR-RT119	round 48" ped table	15	0.000			0.000	0	0	0	0
90	KR-RU	glazed corner unit rutland	10	0.007	30		0.007	0.006798	0.20393334	80.24194	0.545467
91	KR-T102	f/h 4'6"x 3"	1	0.001	6		0.001	0.000684	0.00410397	226.2682	0.154766
92	KR-T103	f/h 4'6"x 2'6"	26	0.018	6		0.018	0.017479	0.10487599	226.2682	3.955016
93	KR-T04	card table	29	0.020	6		0.020	0.019455	0.11673251	226.2682	4.402142
94	KR-T101	blue f/h 6'x 35"	1	0.001	6		0.001	0.000684	0.00410397	226.2682	0.154766
99	KR-TT101	tongue table4'x30"	3	0.002	9		0.002	0.002049	0.01844255	145.0149	0.29716
100	KR-TT102	tongue table4.5'x30" thin	3	0.002	9		0.002	0.002049	0.01844255	145.0149	0.29716
101	KR-TT110	tongue table5'x37"	1	0.001	9		0.001	0.000684	0.00615595	145.0149	0.099189
102	KR-TT111	tongue table6'x37" 1.5	6	0.004	9		0.004	0.00409	0.0368092	145.0149	0.593098
103	KR-TT139	tongue table6'x37" 1.5 e	1	0.001	9		0.001	0.000684	0.00615595	145.0149	0.099189
104	KR-TT165	8'x41" refectory table	1	0.001	12		0.001	0.000684	0.00820793	81.76162	0.055924
105	LANE 04	gothic dresser	10	0.007	54		0.007	0.006798	0.36708001	1086.216	7.383853
106	LANE27	cricket table waxed	12	0.008		as prev		0	0	0	0
107	LANE39	astral glazed bookcase	22	0.015	36		0.015	0.014831	0.5339315	223.7354	3.318316
108	LANE46	console table	1	0.001	9		0.001	0.000684	0.00615595	145.0149	0.099189
109	MACY10	coffee table	59	0.040	6		0.040	0.038752	0.23251493	226.2682	8.768455
110	MACY11	end table	6	0.004	6		0.004	0.00409	0.02453946	226.2682	0.925417
111	SOFA03	cross board table 6x44	1	0.001	21		0.001	0.000684	0.01436388	0.001782	1.22E-06
112	SOFA04	cross board table 7x44	2	0.001	21		0.001	0.001367	0.02870808	0.001782	2.44E-06
113	SOFA05	salemes bed	3	0.002	27		0.002	0.002049	0.05532764	35.49522	0.072736
		total number of products	1461				zeros	0.113484		442.7747	50.24764
									21.04221		18.08547
											put in zeros

		CALCULATIONS FOR CNC									
	Code	Desc.	No.	occur(p)	steup dur						
						same as	sum prob	p(1-p)	dur.p(1-p)	(x-x)^2	sd calc
1	C-PAFF 03	small bookcase front fra	17	0.014	60		0.014	0.014271	0.8562436	654.5692	9.341177
2	C-PAFF04	wide bookcase front fra	29	0.025	30		0.025	0.024092	0.72275074	19.49621	0.469697
3	C-Q1070T	Quebec farmhouse top	18	0.015	30		0.015	0.015097	0.45291364	19.49621	0.294337
4	C-Q1080T	Quebec farmhouse top	16	0.014	30		0.014	0.013443	0.40328642	19.49621	0.262085
7	ENIGMA 0	lamp table 20"x20"	4	0.003	30		0.003	0.003396	0.10186639	19.49621	0.0662
9	K-AFHB	farm house base arhous	0	0.000			0.000	0	0	0	0
10	KR-430007	Console	30	0.026	30		0.026	0.024901	0.74702019	19.49621	0.485469
11	KR-430014	cricket table wax	40	0.034	60	******	0.044	0.042331	2.53986865	654.5692	27.70866
12	KR-430095	wash stand	20	0.017	90		0.017	0.016746	1.50710017	3089.642	51.73778
13	KR-430151	leather top writing table	0	0.000			0.000	0	0	0	0
14	KR-430185	cabriole leg end table	11	0.009	90		0.009	0.009282	0.83536969	3089.642	28.6777
15	KR-430214	triangle	12	0.010	60		0.010	0.010117	0.6070192	654.5692	6.622267
16	KR-430286	astragal bookcase	0	0.000			0.000	0	0	0	0
17	KR-AL19	19 drawer chest	20	0.017	30		0.017	0.016746	0.50236672	19.49621	0.326475
18	KR-BALL01	gothic dresser with locks	1	0.001	30	kr-3ddr		0	0	0	0
19	KR-OBOX0	blanket box 24"	13	0.011	30		0.011	0.010951	0.32851911	19.49621	0.213496
20	KR-OBOX0	ottoman 36"	11	0.009	30		0.009	0.009282	0.27845656	19.49621	0.180962
21	KR-OBOX0	ottoman 54"	10	0.009	30		0.009	0.008445	0.25335999	19.49621	0.164652
22	KR-CD01	computer cupboard	17	0.014	30		0.014	0.014271	0.4281218	19.49621	0.278225
23	KR-COBC0	corbel cupboard	13	0.011	30		0.011	0.010951	0.32851911	19.49621	0.213496
24	KR-CTBA3	barley coffee 36"x24"	27	0.023	30	as quebec		0	0	0	0
25	KR-CTB3	barley coffee 42"x30"	29	0.025	30	as quebec		0	0	0	0
26	KR-CTBF	barley coffee 4'x3'	11	0.009	30	as quebec		0	0	0	0
27	KR-CTUSA	quebec coffee table 36"	17	0.014	30		0.037	0.036074	1.08222156	19.49621	0.703307
28	KR-CTUSA	quebec coffee table 42"	36	0.031	30		0.055	0.052301	1.56902536	19.49621	1.019668
29	KR-CTUSF	quebec coffee table 48"	19	0.016	30		0.026	0.024901	0.74702019	19.49621	0.485469
30	KR-BED1	daybed 4'6"	4	0.003	30		0.003	0.003396	0.10186639	19.49621	0.0662
31	KR-BEDB1	daybed 4'6" with back	12	0.010	60		0.010	0.010117	0.6070192	654.5692	6.622267
32	KR-FH101	4'x30" f/h table	20	0.017	30		0.017	0.016746	0.50236672	19.49621	0.326475
33	KR-FH106	4'6"x35" f/h table	20	0.017	30		0.017	0.016746	0.50236672	19.49621	0.326475
34	KR-FH107	5'x35" f/h table	21	0.018	30		0.018	0.017568	0.52702797	19.49621	0.342502
35	KR-FH108	6'x35" f/h table	13	0.011	30		0.011	0.010951	0.32851911	19.49621	0.213496
36	KR-FILE2P	2 drawer filing cabinet	24	0.020	30		0.020	0.020025	0.6007505	19.49621	0.390412
37	KR-G2DDR	gothic 2 door dresser	5	0.004	30		0.004	0.004241	0.12722416	19.49621	0.08268
38	KR-G3DDR	gothic 3 door dresser	5	0.004	30		0.005	0.005085	0.15253839	19.49621	0.099131
39	KR-GCC	glazed corner cupboard	0	0.000			0.000	0	0	0	0
40	KR-GDB2	2-door gothic dresser ba	2	0.002	30		0.002	0.001701	0.05102026	19.49621	0.033157
41	KR-GGBC	gothic glazed book case	0	0.000			0.000	0	0	0	0
42	KR-GGDR3	gothic glazed dresser	0	0.000			0.000	0	0	0	0
43	KR-GGDR4	gothic 4 dresser glazed	4	0.003	30		0.003	0.003396	0.10186639	19.49621	0.0662
44	KR-GRBC	gothic open bookcase	0	0.000			0.000	0	0	0	0
45	KR-JENKIN	gothic glazed see spec	1	0.001	30		0.001	0.000851	0.0255319	19.49621	0.016593
46	KR -LP01L	louis phillipe pot cupboar	15	0.013	30	*****	0.026	0.024901	0.74702019	19.49621	0.485469
47	KR -LP01R	louis phillipe pot cupboar	15	0.013		kr-lp10l		0	0	0	0
48	KR-LP10	louis phillipe double cod	0	0.000			0.000	0	0	0	0
49	KR-LP15	3+1 drawer chest	0	0.000			0.000	0	0	0	0
50	KR-LP22	louis phillipe 2 door war	0	0.000			0.000	0	0	0	0
51	KR-LP40	louis philipe langene c/b	0	0.000			0.000	0	0	0	0
52	KR-MUY02	quebec f/h 5" thick f/h le	20	0.017	30		0.017	0.016746	0.50236672	19.49621	0.326475
53	KR-MUY03	quebec f/h 6" thick f/h le	20	0.017	30		0.017	0.016746	0.50236672	19.49621	0.326475
54	KR-MUY04	coffee table	22	0.019	30		0.019	0.018388	0.55164568	19.49621	0.3585
55	KR-NOVAD	nova bed 4'6"	9	0.008	60		0.008	0.007607	0.45643978	654.5692	4.979523
56	KR-NOVAD	4'6" nova headboard	1	0.001	30		0.001	0.000851	0.0255319	19.49621	0.016593
57	KR-NOVA	nova bed 5'	10	0.009	60		0.009	0.008445	0.50671999	654.5692	5.528055
58	KR-NOVAS	3' nova bed	6	0.005	60		0.005	0.005085	0.30507678	654.5692	3.328231
59	KR-PAO2	panel 2 drawer bedside	14	0.012	30		0.012	0.011783	0.35348508	19.49621	0.229721
60	KR-PA05	panel 2 drawer sidetable	6	0.005	30		0.005	0.005085	0.15253839	19.49621	0.099131
61	KR-PA12	2/3 chest of drawers	9	0.008	30		0.008	0.007607	0.22821989	19.49621	0.148314
62	KR-PA21	1 door wardrobe	0	0.000			0.000	0	0		0
63	KR-PA22	2 door wardrobe	0	0.000			0.000	0	0		0
64	KR-PA23	3 door wardrobe	0	0.000			0.000	0	0		0
65	KR-PA24	4 door wardrobe	0	0.000				0	0	0	0
66	KR-PA30	panel corner cupboard	6	0.005	30		0.005	0.005085	0.15253839	19.49621	0.099131
67	KR-PA35	gerts wardrobe	0	0.000			0.000	0	0		0
68	KR-PA40	panel wellington chest	10	0.009	30		0.009	0.008445	0.25335999	19.49621	0.164652
69	KR-PA50	panel open top bedside/	0	0.000			0.000	0	0		0
70	KR-PABC0	panel bookcase 1962x3	23	0.020	30		0.020	0.019207	0.57621986	19.49621	0.37447
71	KR-PABC0	panel bookcase 40X48X	17	0.014	30		0.014	0.014271	0.4281218	19.49621	0.278225
72	KR-PABC0	panel bookcase narrow	32	0.027	30		0.027	0.026514	0.79542849	19.49621	0.516928
73	KR-PABC0	panel bookcase 82X49X	34	0.029	30		0.029	0.028122	0.84366266	19.49621	0.548274
74	KR-PBS	pot board server	0	0.000			0.000	0	0		0
75	KR-PTBS	butterfly table 5x 37.5	3	0.003	30		0.003	0.002549	0.07646509	19.49621	0.049693
76	KR-PTBT	butterfly table 6'	3	0.003	30		0.003	0.002549	0.07646509	19.49621	0.049693
77	KR-Q1190T	48" round table top	6	0.005	30		0.005	0.005085	0.15253839	19.49621	0.099131
78	KR-Q1406	small bookcase	16	0.014	30		0.014	0.013443	0.40328642	19.49621	0.262085
79	KR-QHTOP	f/h top thick 5'x35"	61	0.052	30		0.052	0.049259	1.47778094	19.49621	0.960371
80	KR-QHTOP	f/h top 6'x35"	25	0.021	30		0.021	0.020841	0.62523762	19.49621	0.406325
81	KR-QDGB4	quebec gothic 4 door ba	4	0.003	30		0.003	0.003396	0.10186639	19.49621	0.0662
82	KR-QGR3	open gothic rack	0	0.000			0.000	0	0		0
83	KR-QGT3	glazed rack 3 door	0	0.000			0.000	0	0		0
84	KR-RBED5	ribbon and bow bed 4'6"	7	0.006	60		0.006	0.005927	0.35561818	654.5692	3.879611

85	KR-RBED6	ribbon and bow bed 5'	8	0.007	60		0.007	0.006768	0.40607251	654.5692	4.430042
86	KR-RBHB6	ribbon and bow headbo	2	0.002	30		0.002	0.001701	0.05102026	19.49621	0.033157
87	KR-RT117	round 35" ped. table	15	0.013	30		0.013	0.012614	0.37840752	19.49621	0.245917
88	KR-RT118	round 42" ped table	15	0.013	30		0.013	0.012614	0.37840752	19.49621	0.245917
89	KR-RT119	round 48" ped table	15	0.013	30		0.013	0.012614	0.37840752	19.49621	0.245917
90	KR-RU	glazed corner unit rutland	10	0.009	30		0.009	0.008445	0.25335999	19.49621	0.164652
91	KR-T102	f/h 4'6"x 3"	1	0.001	30		0.001	0.000851	0.0255319	19.49621	0.016593
92	KR-T103	f/h 4'6"x 2'6"	26	0.022	30		0.022	0.021656	0.6496812	19.49621	0.422211
93	KR-T04	card table	29	0.025	30		0.025	0.024092	0.72275074	19.49621	0.469697
94	KR-T101	blue f/h 6'x 35"	1	0.001	30		0.001	0.000851	0.0255319	19.49621	0.016593
99	KR-TT101	tongue table4'x30"	3	0.003	30		0.003	0.002549	0.07646509	19.49621	0.049693
100	KR-TT102	tongue table4.5'x30" thin	3	0.003	30		0.003	0.002549	0.07646509	19.49621	0.049693
101	KR-TT110	tongue table5'x37"	1	0.001	30		0.001	0.000851	0.0255319	19.49621	0.016593
102	KR-TT111	tongue table6'x37" 1.5	6	0.005	30		0.005	0.005085	0.15253839	19.49621	0.099131
103	KR-TT139	tongue table6'x37" 1.5 e	1	0.001	30		0.001	0.000851	0.0255319	19.49621	0.016593
104	KR-TT165	8'x41" refectory table	1	0.001	30		0.001	0.000851	0.0255319	19.49621	0.016593
105	LANE 04	gothic dresser	10	0.009	30		0.009	0.008445	0.25335999	19.49621	0.164652
106	LANE27	cricket table waxed	12	0.010		KR-430014		0	0	0	0
107	LANE39	astral glazed bookcase	0	0.000			0.000	0	0		0
108	LANE46	console table	1	0.001	90		0.001	0.000851	0.07659569	3089.642	2.629481
109	MACY10	coffee table	59	0.050	30		0.050	0.04773	1.43189753	19.49621	0.930552
110	MACY11	end table	6	0.005	30		0.005	0.005085	0.15253839	19.49621	0.099131
111	SOFA03	cross board table 6x44	1	0.001	90		0.001	0.000851	0.07659569	3089.642	2.629481
112	SOFA04	cross board table 7x44	2	0.002	120		0.002	0.001701	0.20408104	7324.715	12.45696
113	SOFA05	saiemes bed	0				0.000	0	0		0
		total number of products	###		0	zeros		0.024047		1184.423	28.48234
									34.41545		14.67479

	CALCULATIONS FOR D.E.TENONER										
	Code	Desc	No.	occur(p)	steup dur	same as	sum prob	p(1-p)	dur.p(1-p)	(x-x)^2	sd calc
1	C-PAFF 03	small bookcase front fra	0	0.000		****	0.000	0	0	0	0
2	C-PAFF04	wide bookcase front fra	0	0.000		C-PAFF 03		0	0	0	0
3	C-Q1070T	Quebec farmhouse top	0	0.000			0.000	0	0	0	0
4	C-Q1080T	Quebec farmhouse top	0	0.000			0.000	0	0	0	0
7	ENIGMA 0	lamp table 20"x20"	0	0.000			0.000	0	0	0	0
9	K-AFHB	farm house base arhous	0	0.000			0.000	0	0	0	0
10	KR-430007	Console	0	0.000			0.000	0	0	0	0
11	KR-430014	cricket table wax	0	0.000		******	0.000	0	0	0	0
12	KR-430095	wash stand	20	0.146				0	0	0	0
13	KR-430151	leather top writing table	0	0.000			0.000	0	0	0	0
14	KR-430185	cabriole leg end table	0	0.000			0.000	0	0	0	0
15	KR-430214	triangle	0	0.000			0.000	0	0	0	0
16	KR-430286	astragal bookcase	0	0.000			0.000	0	0	0	0
17	KR-AL19	19 drawer chest	20	0.146	60		0.146	0.124674	7.48041984	225.8399	28.15629
18	KR-BALL01	gothic dresser with locks	0	0.000		kr-3ddr		0	0	0	0
19	KR-OBOX0	blanket box 24"	0	0.000			0.000	0	0	0	0
20	KR-OBOX0	ottoman 36"	0	0.000		*****	0.000	0	0	0	0
21	KR-OBOX0	ottoman 54"	0	0.000		KR-OBOX03		0	0	0	0
22	KR-CD01	computer cupboard	0	0.000			0.000	0	0	0	0
23	KR-COBC0	corbel cupboard	0	0.000			0.000	0	0	0	0
24	KR-CTBA3	barley coffee 36"x24"	0	0.000		as quebec		0	0	0	0
25	KR-CTB3	barley coffee 42"x30"	0	0.000		as quebec		0	0	0	0
26	KR-CTBF	barley coffee 4'x3'	0	0.000		as quebec		0	0	0	0
27	KR-CTUSA	quebec coffee table 36"	0	0.000			0.000	0	0	0	0
28	KR-CTUSA	quebec coffee table 42"	0	0.000			0.000	0	0	0	0
29	KR-CTUSF	quebec coffee table 48"	0	0.000			0.000	0	0	0	0
30	KR-BED1	daybed 4'6"	0	0.000		KR-BEDB1		0	0	0	0
31	KR-BEDB1	daybed 4'6" with back	0	0.000		****	0.000	0	0	0	0
32	KR-FH101	4'x30" f/h table	0	0.000		****	0.000	0	0	0	0
33	KR-FH106	4'6"x35" f/h table	0	0.000		KR-FH101		0	0	0	0
34	KR-FH107	5'x35" f/h table	0	0.000		KR-FH101		0	0	0	0
35	KR-FH108	6'x35" f/h table	0	0.000		KR-FH101		0	0	0	0
36	KR-FILE2P	2 drawer filing cabinet	0	0.000			0.000	0	0	0	0
37	KR-G2DDR	gothic 2 door dresser	0	0.000			0.000	0	0	0	0
38	KR-G3DDR	gothic 3 door dresser	0	0.000		*******	0.000	0	0	0	0
39	KR-GCC	glazed corner cupboard	0	0.000			0.000	0	0	0	0
40	KR-GDB2	2-door gothic dresser ba	0	0.000			0.000	0	0	0	0
41	KR-GGBC	gothic glazed book case	0	0.000			0.000	0	0	0	0
42	KR-GGDR3	gothic glazed dresser	0	0.000			0.000	0	0	0	0
43	KR-GGDR4	gothic 4 dresser glazed	0	0.000			0.000	0	0	0	0
44	KR-GRBC	gothic open bookcase	0	0.000			0.000	0	0	0	0
45	KR-JENKIN	gothic glazed see spec	0	0.000			0.000	0	0	0	0
46	KR -LP01L	louis philipe pot cupboar	15	0.109	60	*****	0.219	0.171027	10.2616016	225.8399	38.62466
47	KR -LP01R	louis philipe pot cupboar	15	0.109		kr-lp10l		0	0	0	0
48	KR-LP10	louis philipe double cod	13	0.095	60		0.095	0.085886	5.15317811	225.8399	19.39656
49	KR-LP15	3+1 drawer chest	7	0.051	60		0.051	0.048484	2.90905216	225.8399	10.94967
50	KR-LP22	louis philipe 2 door war	0	0.000			0.000	0	0	0	0
51	KR-LP40	louis philipe langerie c/b	5	0.036	60		0.036	0.035164	2.10986201	225.8399	7.941518
52	KR-MUY02	quebec f/h 5" thick f/h le	0	0.000			0.000	0	0	0	0
53	KR-MUY03	quebec f/h 6" thick f/h le	0	0.000			0.000	0	0	0	0
54	KR-MUY04	coffee table	0	0.000			0.000	0	0	0	0
55	KR-NOVAD	nova bed 4'6"	0	0.000			0.000	0	0	0	0
56	KR-NOVAD	4'6" nova headboard	0	0.000		****	0.000	0	0	0	0
57	KR-NOVA	nova bed 5'	0	0.000		KR-NOVAD		0	0	0	0
58	KR-NOVAS	3' nova bed	0	0.000		KR-NOVAD		0	0	0	0
59	KR-PAO2	panel 2 drawer bedside	14	0.102	60		0.102	0.091747	5.50482178	225.8399	20.72014
60	KR-PA05	panel 2 drawer sidetable	6	0.044	60		0.044	0.041878	2.51265384	225.8399	9.457626
61	KR-PA12	2/3 chest of drawers	9	0.066	60		0.066	0.061378	3.68266823	225.8399	13.86156
62	KR-PA21	1 door wardrobe	0	0.000			0.000	0	0	0	0
63	KR-PA22	2 door wardrobe	0	0.000			0.000	0	0	0	0
64	KR-PA23	3 door wardrobe	0	0.000		*****	0.000	0	0	0	0
65	KR-PA24	4 door wardrobe	0	0.000		KR-PA23		0	0	0	0
66	KR-PA30	panel corner cupboard	0	0.000			0.000	0	0	0	0
67	KR-PA35	gents wardrobe	0	0.000			0.000	0	0	0	0
68	KR-PA40	panel wellington chest	10	0.073	60		0.073	0.067665	4.05988598	225.8399	15.28141
69	KR-PA50	panel open top bedside/	0	0.000			0.000	0	0	0	0
70	KR-PABC0	panel bookcase 1962x3	0	0.000			0.000	0	0	0	0
71	KR-PABC0	panel bookcase 40X48X	0	0.000			0.000	0	0	0	0
72	KR-PABC0	panel bookcase narrow	0	0.000		C-PAFF 03		0	0	0	0
73	KR-PABC0	panel bookcase 82X49X	0	0.000		C-PAFF 03		0	0	0	0
74	KR-PBS	pot board server	0	0.000			0.000	0	0	0	0
75	KR-PTBS	butterfly table 5x 37.5	0	0.000		****	0.000	0	0	0	0
76	KR-PTBT	butterfly table 6'	0	0.000		KR-PTBS		0	0	0	0
77	KR-Q1190T	48" round table top	0	0.000			0.000	0	0	0	0
78	KR-Q1406	small bookcase	0	0.000			0.000	0	0	0	0
79	KR-QHTOP	f/h top thick 5'x35"	0	0.000		KR-FH101		0	0	0	0
80	KR-QHTOP	f/h top 6'x35"	0	0.000		KR-FH101		0	0	0	0
81	KR-QDGB4	quebec gothic 4 door ba	0	0.000			0.000	0	0	0	0
82	KR-QGR3	open gothic rack	0	0.000			0.000	0	0	0	0
83	KR-QGT3	glazed rack 3 door	0	0.000			0.000	0	0	0	0
84	KR-RBED5	ribbon and bow bed 4'6"	0	0.000		****	0.000	0	0	0	0

85	KR-RBED6	ribbon and bow bed 5'	0	0.000		KR-RBED54		0	0	0	0
86	KR-RBHB6	ribbon and bow headbo	0	0.000			0.000	0	0	0	0
87	KR-RT117	round 35" ped. table	0	0.000			0.000	0	0	0	0
88	KR-RT118	round 42" ped table	0	0.000			0.000	0	0	0	0
89	KR-RT119	round 48" ped table	0	0.000			0.000	0	0	0	0
90	KR-RU	glazed corner unit rutland	0	0.000			0.000	0	0	0	0
91	KR-T102	f/h 4'6"x 3"	0	0.000		KR-FH101		0	0	0	0
92	KR-T103	f/h 4'6"x 2'6"	0	0.000		KR-FH101		0	0	0	0
93	KR-T04	card table	0	0.000				0	0	0	0
94	KR-T101	blue f/h 6'x 35"	0	0.000		KR-FH101		0	0	0	0
95	KR-TFHJ4	f/h table 5'x35"	0	0.000		KR-FH101		0	0	0	0
96	KR-TFHK4	f/h table 6'x35"	0	0.000		KR-FH101		0	0	0	0
97	KR-TFHL4	f/h table 6'x40"	0	0.000		KR-FH101		0	0	0	0
98	KR-TFHN4	f/h table 7'x40"	0	0.000		KR-FH101		0	0	0	0
99	KR-TT101	tongue table4'x30"	0	0.000			0.000	0	0	0	0
100	KR-TT102	tongue table4.5'x30" thin	0	0.000			0.000	0	0	0	0
101	KR-TT110	tongue table5'x37"	0	0.000			0.000	0	0	0	0
102	KR-TT111	tongue table6'x37" 1.5	0	0.000			0.000	0	0	0	0
103	KR-TT139	tongue table6'x37" 1.5 e	0	0.000			0.000	0	0	0	0
104	KR-TT165	8'x41" refectory table	0	0.000			0.000	0	0	0	0
105	LANE 04	gothic dresser	0	0.000			0.000	0	0	0	0
106	LANE27	cricket table waxed	0	0.000		KR-430014		0	0	0	0
107	LANE39	astral glazed bookcase	0	0.000			0.000	0	0	0	0
108	LANE46	console table	0	0.000			0.000	0	0	0	0
109	MACY10	coffee table	0	0.000			0.000	0	0	0	0
110	MACY11	end table	0	0.000			0.000	0	0	0	0
111	SOFA03	cross board table 6x44	1	0.007	60		0.007	0.007246	0.43475944	225.8399	1.636434
112	SOFA04	cross board table 7x44	2	0.015	60		0.015	0.014385	0.86312537	225.8399	3.248803
113	SOFA05	salernes bed	0	0.000			0.000	0	0	0	0
		total number of products	137		0	zeros		0.250466		2022.483	506.5637
									44.97203		12.8851

	Code	Desc	No.	occur(p)	steup dur						
						same as	sum prob	p(1-p)	dur.p(1-p)	(x-x)^2	sd calc
1	C-PAFF 03	small bookcase front fra	17	0.048	20	****	0.431	0.245183	4.90365864	109.0003	26.72502
2	C-PAFF04	wide bookcase front fra	29	0.082	20	C-PAFF 03		0	0	0	0
3	C-Q1070T	Quebec farmhouse top	0	0.000			0.000	0	0	0	0
4	C-Q1080T	Quebec farmhouse top	0	0.000			0.000	0	0	0	0
7	ENIGMA 0	lamp table 20"x20"	0	0.000			0.000	0	0	0	0
9	K-AFHB	farm house base arhous	0	0.000			0.000	0	0	0	0
10	KR-430007	Consele	0	0.000			0.000	0	0	0	0
11	KR-430014	cricket table wax	0	0.000		******	0.000	0	0	0	0
12	KR-430095	wash stand	0	0.000				0	0	0	0
13	KR-430151	leather top writing table	0	0.000			0.000	0	0	0	0
14	KR-430185	cabriole leg end table	0	0.000			0.000	0	0	0	0
15	KR-430214	triangle	0	0.000			0.000	0	0	0	0
16	KR-430286	astragal bookcase	0	0.000			0.000	0	0	0	0
17	KR-AL19	19 drawer chest	0	0.000			0.000	0	0	0	0
18	KR-BALL01	gothic dresser with locks	1	0.003		kr-3ddr		0	0	0	0
19	KR-OBOX0	blanket box 24"	0	0.000	20		0.000	0	0	0	0
20	KR-OBOX0	ottoman 36"	0	0.000		*****	0.000	0	0	0	0
21	KR-OBOX0	ottoman 54"	0	0.000		KR-OBOX03		0	0	0	0
22	KR-CD01	computer cupboard	0	0.000			0.000	0	0	0	0
23	KR-COBC0	corbel cupboard	0	0.000			0.000	0	0	0	0
24	KR-CTBA3	barley coffee 36"x24"	0	0.000		as quebec		0	0	0	0
25	KR-CTB3	barley coffee 42"x30"	0	0.000		as quebec		0	0	0	0
26	KR-CTBF	barley coffee 4'x3'	0	0.000		as quebec		0	0	0	0
27	KR-CTUSA	quebec coffee table 36"	0	0.000			0.000	0	0	0	0
28	KR-CTUSA	quebec coffee table 42"	0	0.000			0.000	0	0	0	0
29	KR-CTUSF	quebec coffee table 48"	0	0.000			0.000	0	0	0	0
30	KR-BED1	daybed 4'6"	4	0.011	11	KR-BEDB1		0	0	0	0
31	KR-BEDB1	daybed 4'6" with back	12	0.034	11	****	0.045	0.043271	0.47598488	2.074526	0.089768
32	KR-FH101	4'x30" f/h table	0	0.000		****	0.244	0.184272	0	0	0
33	KR-FH106	4'6"x35" f/h table	0	0.000		KR-FH101		0	0	0	0
34	KR-FH107	5'x35" f/h table	0	0.000		KR-FH101		0	0	0	0
35	KR-FH108	6'x35" f/h table	0	0.000		KR-FH101		0	0	0	0
36	KR-FILE2P	2 drawer filing cabinet	0	0.000			0.000	0	0	0	0
37	KR-G2DDR	gothic 2 door dresser	5	0.014	11		0.014	0.013964	0.15360046	2.074526	0.028968
38	KR-G3DDR	gothic 3 door dresser	5	0.014	11		0.042	0.040687	0.44755997	2.074526	0.084407
39	KR-GCC	glazed corner cupboard	0	0.000			0.000	0	0	0	0
40	KR-GDB2	2-door gothic dresser ba	0	0.000			0.000	0	0	0	0
41	KR-GGBC	gothic glazed book case	0	0.000			0.000	0	0	0	0
42	KR-GGDR3	gothic glazed dresser	0	0.000			0.000	0	0	0	0
43	KR-GGDR4	gothic 4 dresser glazed	0	0.000			0.000	0	0	0	0
44	KR-GRBC	gothic open bookcase	10	0.028	20		0.028	0.027526	0.55052203	109.0003	3.000354
45	KR-JENKIN	gothic glazed see spec	0	0.000			0.000	0	0	0	0
46	KR -LP01L	louis phillipe pot cupboar	0	0.000			0.000	0	0	0	0
47	KR -LP01R	louis phillipe pot cupboar	0	0.000		kr-lp10l		0	0	0	0
48	KR-LP10	louis phillipe double cod	0	0.000			0.000	0	0	0	0
49	KR-LP15	3+1 drawer chest	0	0.000			0.000	0	0	0	0
50	KR-LP22	louis phillipe 2 door war	0	0.000			0.000	0	0	0	0
51	KR-LP40	louis phillipe langene c/b	0	0.000			0.000	0	0	0	0
52	KR-MUY02	quebec f/h 5" thick f/h le	0	0.000			0.000	0	0	0	0
53	KR-MUY03	quebec f/h 6" thick f/h le	0	0.000			0.000	0	0	0	0
54	KR-MUY04	coffee table	0	0.000			0.000	0	0	0	0
55	KR-NOVAD	nova bed 4'6"	0	0.000			0.000	0	0	0	0
56	KR-NOVAD	4'6" nova headboard	0	0.000			0.000	0	0	0	0
57	KR-NOVA	nova bed 5'	0	0.000		KR-NOVAD		0	0	0	0
58	KR-NOVAS	3' nova bed	0	0.000		KR-NOVAD		0	0	0	0
59	KR-PAO2	panel 2 drawer bedside	0	0.000			0.000	0	0	0	0
60	KR-PA05	panel 2 drawer sidetable	0	0.000			0.000	0	0	0	0
61	KR-PA12	2/3 chest of drawers	0	0.000			0.000	0	0	0	0
62	KR-PA21	1 door wardrobe	0	0.000			0.000	0	0	0	0
63	KR-PA22	2 door wardrobe	0	0.000			0.000	0	0	0	0
64	KR-PA23	3 door wardrobe	0	0.000			0.000	0	0	0	0
65	KR-PA24	4 door wardrobe	0	0.000		KR-PA23		0	0	0	0
66	KR-PA30	panel corner cupboard	6	0.017	11		0.017	0.016708	0.1837909	2.074526	0.034662
67	KR-PA35	gents wardrobe	12	0.034	22		0.034	0.032839	0.72245183	154.7616	5.082173
68	KR-PA40	panel wellington chest	0	0.000			0.000	0	0	0	0
69	KR-PA50	panel open top bedside/	14	0.040	20		0.040	0.038087	0.76174273	109.0003	4.15151
70	KR-PABC0	panel bookcase 1962x3	23	0.065	20	C-PAFF 03	0.000	0	0	0	0
71	KR-PABC0	panel bookcase 40X48X	17	0.048	20	C-PAFF 03	0.000	0	0	0	0
72	KR-PABC0	panel bookcase narrow	32	0.091		C-PAFF 03		0	0	0	0
73	KR-PABC0	panel bookcase 82X49X	34	0.096		C-PAFF 03		0	0	0	0
74	KR-PBS	pot board server	0	0.000			0.000	0	0	0	0
75	KR-PTBS	butterfly table 5x 37.5	0	0.000			0.000	0	0	0	0
76	KR-PTBT	butterfly table 6'	0	0.000		KR-PTBS		0	0	0	0
77	KR-Q1190T	48" round table top	0	0.000			0.000	0	0	0	0
78	KR-Q1406	small bookcase	16	0.045	11		0.045	0.043271	0.47598488	2.074526	0.089768
79	KR-QHTOP	f/h top thick 5'x35"	61	0.173		KR-FH101		0	0	0	0
80	KR-QHTOP	f/h top 6'x35"	25	0.071		KR-FH101		0	0	0	0
81	KR-QDGB4	quebec gothic 4 door ba	0	0.000			0.000	0	0	0	0
82	KR-QGR3	open gothic rack	9	0.025		KR-G3DDR	0.025	0.024846	0	0	0
83	KR-QGT3	glazed rack 3 door	0	0.000			0.000	0	0	0	0
84	KR-RBED5	ribbon and bow bed 4'6"	0	0.000			0.000	0	0	0	0
85	KR-RBED6	ribbon and bow bed 5'	0	0.000		KR-RBED54		0	0	0	0

86	KR-RBHB6	ribbon and bow headbo	0	0.000			0.000	0	0	0	0
87	KR-RT117	round 35" ped. table	0	0.000			0.000	0	0	0	0
88	KR-RT118	round 42" ped table	0	0.000			0.000	0	0	0	0
89	KR-RT119	round 48" ped table	0	0.000			0.000	0	0	0	0
90	KR-RU	glazed corner unit rutland	10	0.028	20		0.028	0.027526	0.55052203	109.0003	3.000354
91	KR-T102	f/h 4'6"x 3"	0	0.000		KR-FH101		0	0	0	0
92	KR-T103	f/h 4'6"x 2'6"	0	0.000		KR-FH101		0	0	0	0
93	KR-T04	card table	0	0.000				0	0	0	0
94	KR-T101	blue f/h 6'x 35"	0	0.000		KR-FH101		0	0	0	0
99	KR-TT101	tongue table4'x30"	0	0.000			0.000	0	0	0	0
100	KR-TT102	tongue table4.5'x30" thin	0	0.000			0.000	0	0	0	0
101	KR-TT110	tongue table5'x37"	0	0.000			0.000	0	0	0	0
102	KR-TT111	tongue table6'x37" 1.5	0	0.000			0.000	0	0	0	0
103	KR-TT139	tongue table6'x37" 1.5 e	0	0.000			0.000	0	0	0	0
104	KR-TT165	8'x41" refectory table	0	0.000			0.000	0	0	0	0
105	LANE 04	gothic dresser	10	0.028	11		0.028	0.027526	0.30278712	2.074526	0.057104
106	LANE27	cricket table waxed	0	0.000		KR-430014		0	0	0	0
107	LANE39	astral glazed bookcase	0	0.000			0.000	0	0	0	0
108	LANE46	console table	1	0.003	11		0.003	0.002825	0.0310732	2.074526	0.00586
109	MACY10	coffee table	0	0.000			0.000	0	0	0	0
110	MACY11	end table	0	0.000			0.000	0	0	0	0
111	SOFA03	cross board table 6x44	0	0.000			0.000	0	0	0	0
112	SOFA04	cross board table 7x44	0	0.000			0.000	0	0	0	0
113	SOFA05	salernes bed	0	0.000			0.000	0	0	0	0
		total number of products	353		0		zeros	0.231468		91.38746	21.15327
									9.559679		7.96889

	FINAL CALCULATIONS FOR RK						
					mean	var	sd
Resaw	2.091931	1.713929	No for thickness	multiply mean and var by 1.190	2.489398	3.495688	1.869676
Dimter	2.789241	2.285239			3.319197	6.214558	2.492901
Planer/mo	25.15871	17.67146	Yes	None required	25.15871	312.2805	17.67146
Press	3.919013	2.686506	No for subset	No. going through 1431	3.83854	7.069115	2.658781
Sander	11.96195	0.676093	Yes	None required	11.96195	0.457102	0.676093
CNC	34.41545	14.67479	No for subset	No. going through 1154	27.18373	170.0981	13.04217
Dimension	21.04221	18.08547	Yes	1461	21.04221	327.0842	18.08547
Double En	44.97203	12.8851	No for subset	No. going through 137	4.21709	15.56847	3.94569
Spindle	9.559679	7.96889	No for subset	No. going through 353	2.309765	15.34335	3.917059
			Grand tot mean		101.5206	857.6111	29.285

APPENDIX
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ON INSTRUCTION
FROM
THE UNIVERSITY